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LANSCE
Los Alamos Neutron Science Center

Los Alamos Neutron Science Center Division

Annual Self–Assessment

January 1999 to December 1999

April 2000

Los Alamos
NATIONAL LABORATORY

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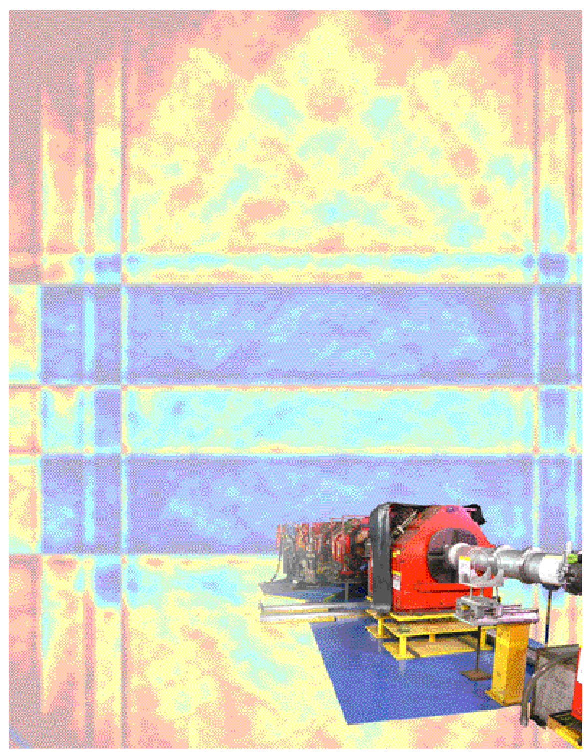

▲ *About the front cover: The background is a tomographic reconstruction from twelve fast neutron radiographs of two iron plates separated by a half-inch gap (p. 25). The foreground image shows the proton radiography beam line in Area C (p. 23).*

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LANSCE Self-Assessment

Abstract

The Los Alamos Neutron Science Center self-assessment describes scientific and technological progress and achievements in LANSCE Division during the period of January 1999 through December 1999. The report includes a Division overview; organizational descriptions; FY99 budget information; a discussion of the safety stand down; operation of the LANSCE User Facility; noteworthy scientific, technical, and programmatic achievements in neutron scattering, radiography, nuclear science, and accelerator science and technology; facility upgrade projects; and performance indicators.

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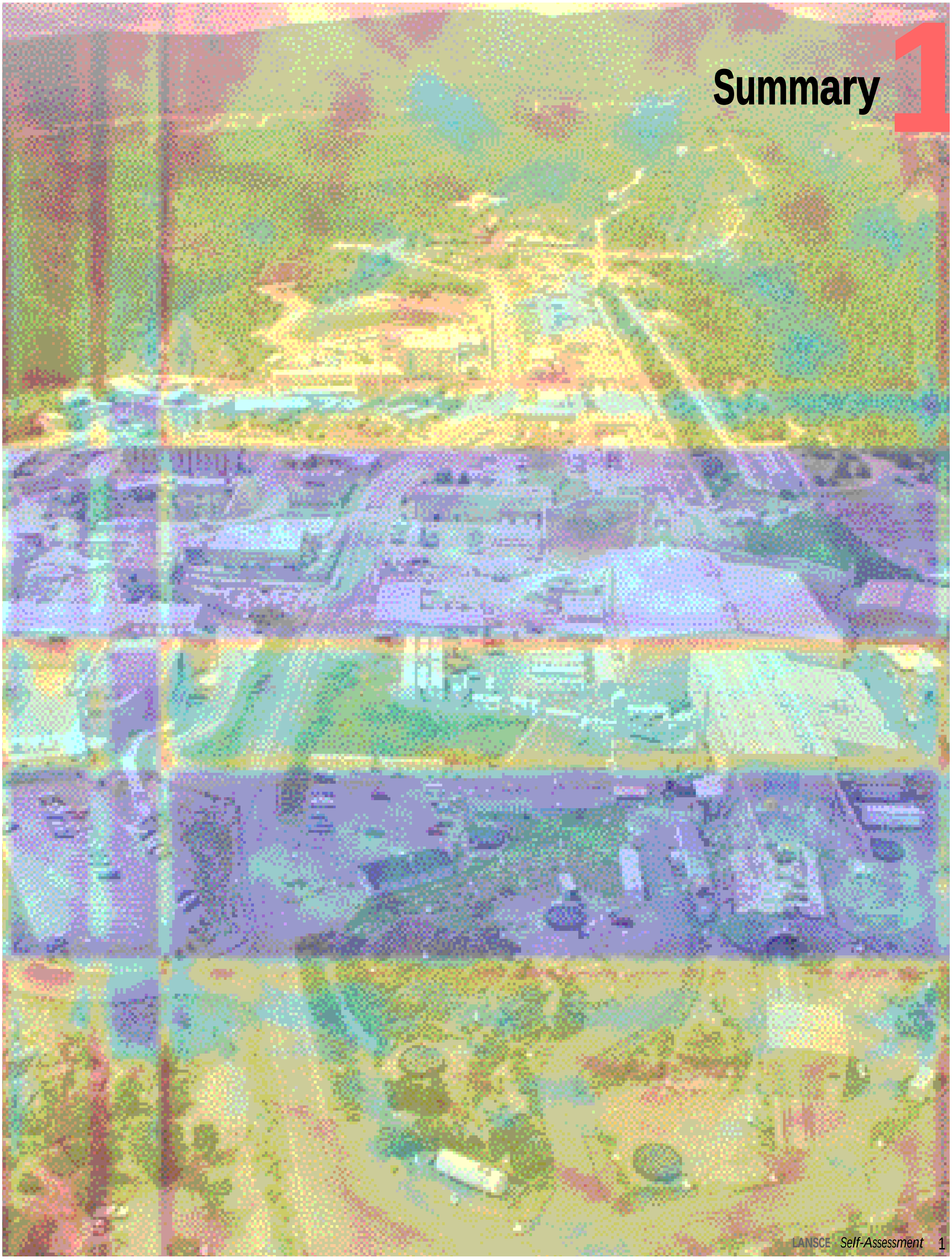
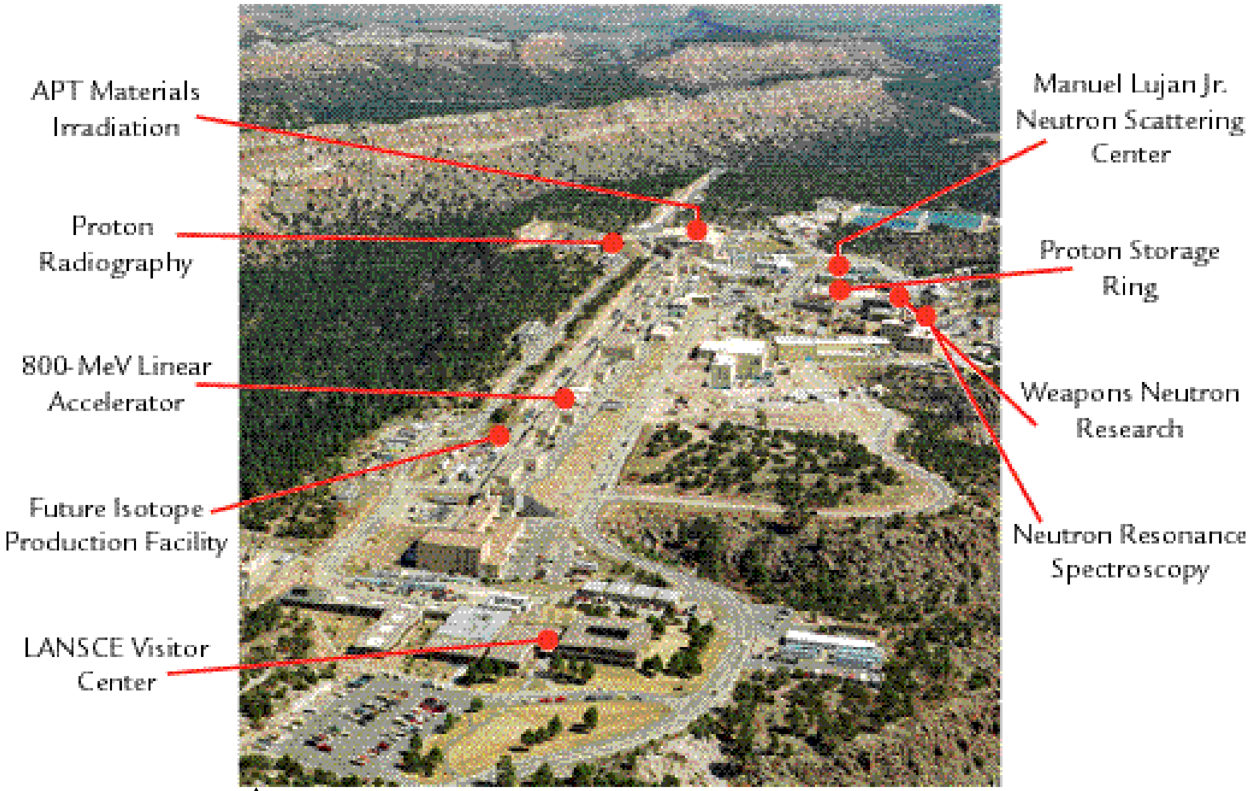




▲*The Los Alamos Neutron Science Center (LANSCE) Division is the primary occupant of Technical Area 53 (TA-53) at the Los Alamos National Laboratory.*

1 SUMMARY

1.1 Division Overview

The Los Alamos Neutron Science Center (LANSCE) Division is a center of excellence for the application of accelerator technology and spallation neutron sources to defense and civilian research. The wide range of activities conducted in LANSCE Division can be divided into five synergistic categories:

- operation of the LANSCE accelerator complex and experimental areas as a National User Facility for defense and civilian research using neutrons and protons;
- research activities in neutron scattering and neutron nuclear science in support of stockpile stewardship and basic scientific investigations (often in collaboration with users who are not members of LANSCE Division);
- projects, such as the Short-Pulse Spallation Source (SPSS) Enhancement Project and the Isotope Production Facility (IPF), to improve the capabilities of the LANSCE User Facility;
- national projects, such as the Accelerator Production of Tritium (APT) and the Spallation Neutron Source (SNS) linear accelerator, where the core competencies of the division are applied to design and build hardware and software that will not be part of the LANSCE User Facility; and
- advanced-accelerator-technology projects in areas such as high-power microwaves and free-electron lasers.

1.2 Organizational Descriptions

LANSCE Division Office (LANSCE- DO). The Division Office is responsible for management of the division, strategic planning, interface with Los Alamos National Laboratory (LANL) and the Department of Energy (DOE), oversight and management of major projects and programs, administration of the user program, and personnel management.

Accelerator Physics and Engineering (LANSCE-1). LANSCE-1 provides technologies to produce high-performance accelerator systems for future projects at LANL and for applications of national importance. The group performs research and development to advance the state of the art in accelerator physics and engineering design and analysis.

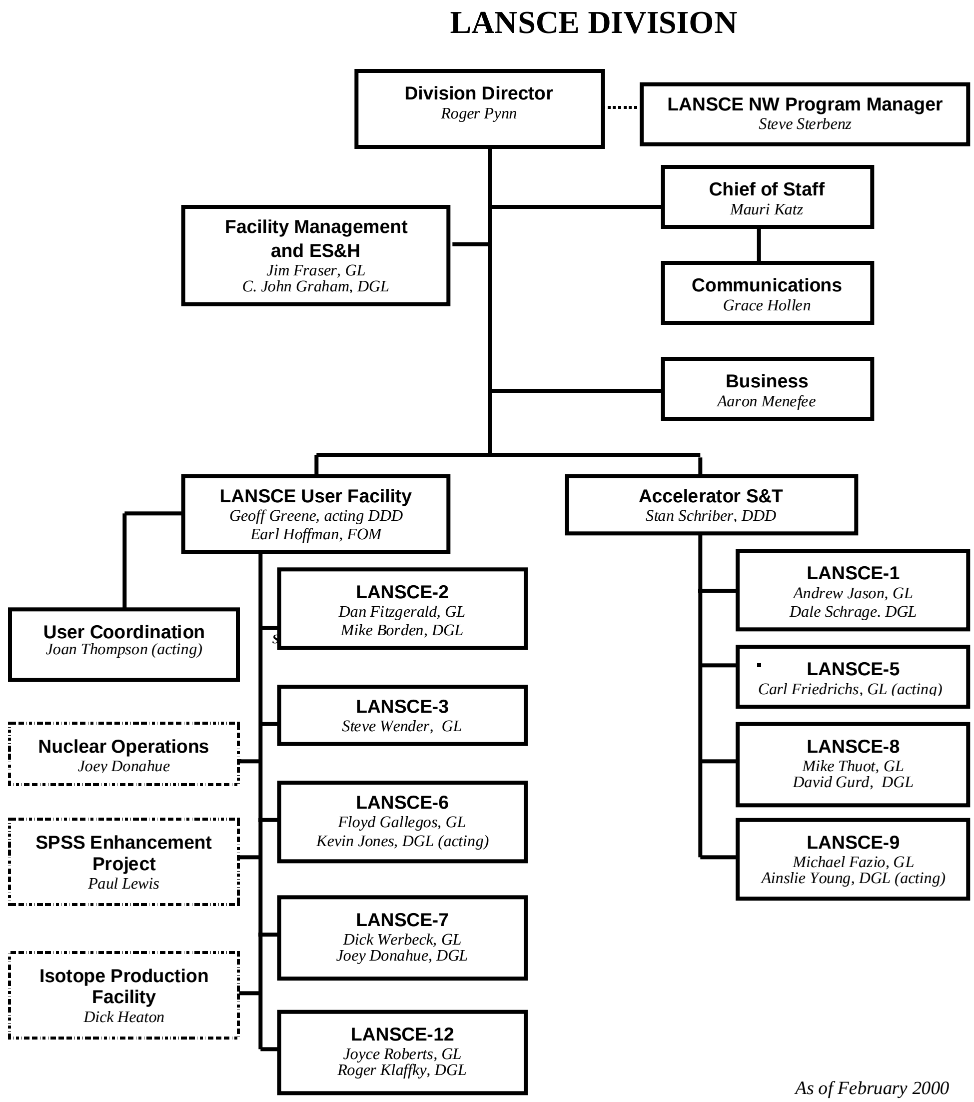
Accelerator Maintenance and Development (LANSCE-2). LANSCE-2 maintains the equipment associated with the LANSCE beam delivery complex and develops new accelerator and beam-delivery capabilities. The group has a major responsibility to improve operation of the ion sources, linac systems, Proton Storage Ring (PSR), beam transfer lines, and beam diagnostics.

Neutron and Nuclear Science (LANSCE-3). LANSCE-3 operates the Weapons Neutron Research (WNR) facility and several flight paths at the Lujan Center that are used for nuclear-science research. The group carries out nuclear-physics experiments using these facilities.

rf Accelerator Technology (LANSCE-5). LANSCE-5 develops, constructs, operates, and maintains radio-frequency (rf) systems for the LANSCE accelerator and other related applications. LANSCE-5 supports rf system design and technology development for SNS, APT, and microwave materials processing.

Accelerator Operations and Technical Support (LANSCE-6). LANSCE-6 is responsible for operating the LANSCE accelerator and beam-delivery systems and for developing safe operating procedures for these facilities.

High-Intensity Beam Lines, Accelerator Experimental Areas, and Remote Handling (LANSCE-7). LANSCE-7 is responsible for the safe operation of the Lujan Center spallation target, the design and operation of remote-handling systems used to install new components and maintain highly activated components, and the transportation of highly activated components.



▲ **FIGURE 1**. *LANSCE Division Organization Chart.*

Accelerator Controls and Automation (LANSCE-8). LANSCE-8 produces automated control systems, software tools, and support services for electronic design and computer networks for LANSCE Division and the domestic and international accelerator and astronomy communities. The group's primary products are control systems and control technology based on the Experimental Physics and Industrial Control System (EPICS) software tool kit. LANSCE-8 is leading the project-wide SNS accelerator-controls effort.

High-Power Microwaves, Advanced Accelerators, and Electrodynamic Applications (LANSCE-9). LANSCE-9 applies microwave and accelerator science and technology in the areas of high-power microwave sources and effects, advanced accelerators, microwave-driven chemistry, theory and modeling of complex three-dimensional electro-magnetic systems and structures, and electrodynamic applications. LANSCE-9 maintains several important LANL facilities: the Advanced Free Electron Laser (AFEL) facility; the Sub-Picosecond Accelerator (SPA) facility; the BANSHEE high-power modulator testbed for high-power rf (HPRF) tube development; the TA-49 Antenna and Pulse Power Outdoor Range; the TA-35 induction linac injector test stand; and the TA-33 Electromagnetic Effects Test Bunker Complex.

Manuel Lujan Jr. Neutron Scattering Center (LANSCE-12). LANSCE-12 carries out neutron-scattering experiments at the Manuel Lujan Jr. Neutron Scattering Center in support of defense and basic research programs. The group provides support to external users of the Lujan Center.

LANSCE-FM. The Facility Management group provides ES&H and training support to all LANSCE groups and is responsible for the maintenance and operation of conventional facilities for the entire TA-53 technical area. The activities of a team of radiological control technicians from ESH-1 are coordinated by LANSCE-FM.

LANSCE User Program Coordination Office. This office administers the user program for the LANSCE User Facility, assists the LANSCE Users Group with organizing its annual meeting, and maintains statistics on facility usage that are required by our DOE sponsors.

LANSCE Communication Team. The LANSCE Communication team consists of communication specialists from CIC and LANSCE Divisions. The team produces a variety of communication products about LANSCE research and technology to reach a broad audience that includes the user community, researchers from academia and industry, program sponsors, and Laboratory management.

TABLE 1. *Employee Profile.*

Title	LANSCE UC Employees	UC Employees Deployed to LANSCE	LANSCE Contract Employees	Contract Employees Deployed to LANSCE	
Technical Staff Members	165	26	7	7	
Technicians	136	21	20	42	
Administrative	29	7	8	12	
TOTALS	**330**	**54**	**35**	**61**	**480**

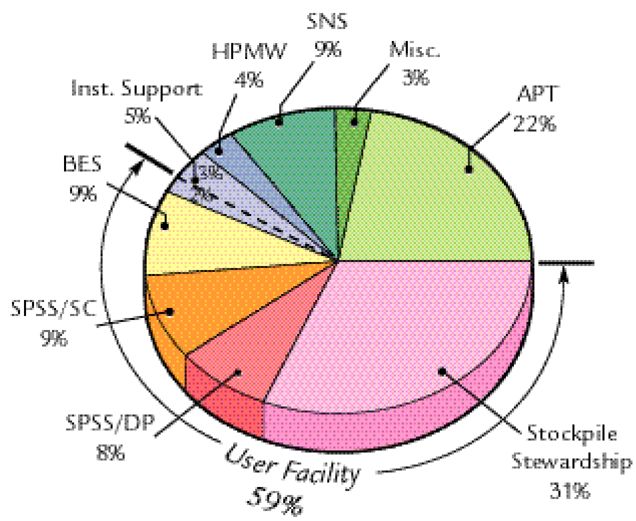
1.3 FY99 Budget

TABLE 2. *LANSCE User Facility Laboratory-Directed Research and Development (LDRD).*

Projects	FY99
Neutron and Accelerator-Based Science	$1.2M
Advanced Research Capabilities for Neutron Scattering	$0.9M
Single PI Experiments	$0.7M
Total	**$2.8M**
Other Related LDRD Projects*	**FY99**
Ultra-cold Neutron Science	$0.9M
Advanced Dynamic Radiography with Protons	$1.0M
Total	**$1.9M**

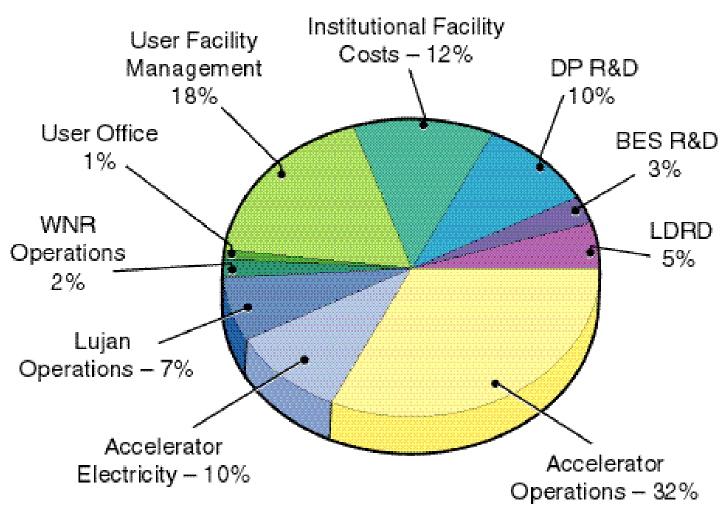
* Funds administered by P Division for R&D at LANSCE.

The FY99 LANSCE Division budget ($115M) indicates funding from a diverse set of programmatic sponsors (see Figure 2). In FY99, there was slight growth in the Stockpile Stewardship area over previous years. The APT Project continued to provide almost a quarter of the division's funding. LANSCE expects the amount of APT Project funding to drop substantially over the next few years. The SPSS Enhancement Project activities (funded by DOE/DP and DOE/SC) will also diminish in future years as this project is completed.



▲ **FIGURE 2.** *FY99 LANSCEDivision funding ($115M) by programmatic source. This budget includes operating, capital, and construction activities. Roughly 59% of the LANSCE Division budget is directly attributable to User Facility activities.*

The LANSCE User Facility operating budget is dedicated to operating the LANSCE accelerator, PSR, and experimental areas (Lujan, WNR and PRAD). The pie chart in Figure 3 illustrates the functional activities supported by the FY99 User Facility operating budget. The User Facility budget is directly supported by DOE/DP, DOE/SC, LDRD, and contributions by the APT Project for use of the LANSCE experimental capabilities. Besides direct programmatic allocations, a portion of the facility management budget is collected through an indirect (tax) mechanism against all programs at LANSCE.

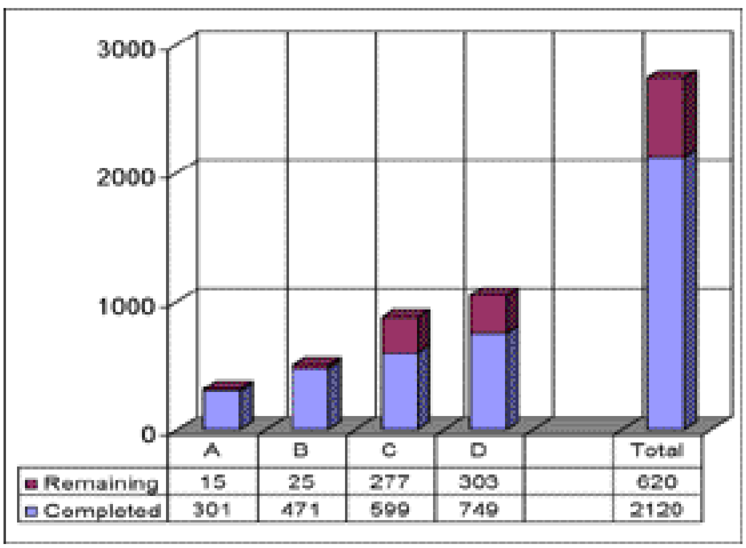


▲ **FIGURE 3.** *FY99 LANSCE User Facility operating budget ($58M). This budget includes funding that resides within LANSCE and other Laboratory divisions. It does not include the SPSS Enhancement Project and infrastructure projects.*

1.4 Safety Stand Down

On February 5, 1999, the LANSCE Division Director, who is also the Landlord for Technical Area 53, stood down programmatic activity at TA-53 following six reportable occurrences during the month of January (the historical rate of such occurrences at TA-53 is close to one per month). Although none of the occurrences resulted in significant injury or environmental impact, their number and nature indicated systemic safety and operating problems, including a culture of informality, a disregard for safe operating procedures, and poor communication between teams working in the same area. Following the stand down, programmatic activities were restarted in a systematic and formal way that involved workers and supervisors accomplishing the following steps:

- confirmation of required training, including on-the-job training and retraining as necessary;
- identification and correction of safety problems involving physical plant (see Figure 4);
- thorough reevaluation and, if necessary, correction of Hazard Control Plans and work procedures;
- independent verification of the safety of all activities with medium or higher initial hazards;
- re-education of workers about their responsibilities for safe work; and
- reauthorization of all work by appropriate levels of management.



▲ **FIGURE 4.** *LANSCE employees identified 2,740 safety issues during the safety stand down. These safety issues varied in seriousness from Category A (i.e., needs to be corrected before restart of the relevant activity) to Category D (i.e., minimal safety impact). As of January 2000, we had corrected 2,120 identified deficiencies.*

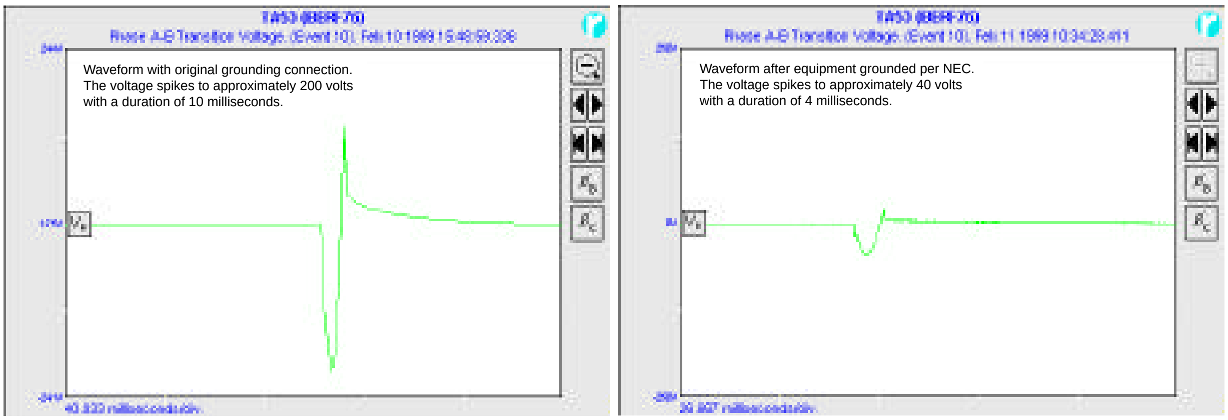
A representative of the DOE Los Alamos Area Office observed restart activities on a daily basis and provided DOE concurrence with each restart activity.

The effort required to complete the work restart process described above varied according to the potential hazards associated with a group's activities, from about 3 man months for LANSCE-1 to over 75 man months for LANSCE-6. The total cost of the safety stand down in manpower lost to programmatic activity was $6 million.

The following is a list of major safety-improvement activities conducted during the safety stand down:

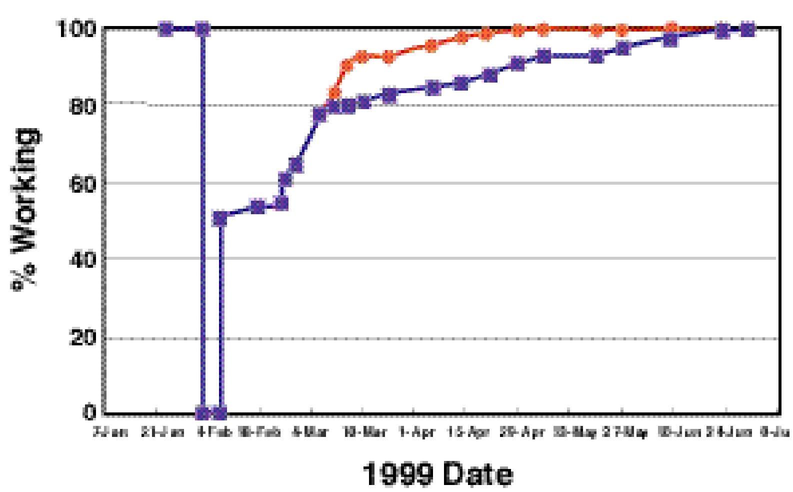
- ground-fault corrections that affected the entire PSR Ring Equipment building (approximately 3 man-months) (see Figure 5);
- Personnel Access Control System (PACS) upgrades in all experimental areas to meet modern standards (30 man-months);

- removal of potentially hazardous legacy equipment from the proton radiography (PRAD) facility and the magnet staging area (32 man months);
- removal of legacy equipment from the Lujan spallation target area (12 man months);
- sealing of the Lujan target area to prevent water spills spreading to experimental areas (8 man months);
- bringing fire protection to code and improvement of pressure safety of the Lujan hydrogen moderator system (18 man months); and
- installation of four newly designed mercury shutters at the Lujan Center (12 man months).



▲ **FIGURE 5.** *In the Ring Equipment Building (REB) the grounding conductor was separated from the phase conductors in violation of NEC code. This separation raises the impedance of the equipment ground and, in the event of a phase-to-ground fault, would allow the case of a piece of equipment to reach high voltages. Experiments in a worst-case scenario with a large load and a long path to the common-ground point (left-hand graph) found a peak voltage of 200 volts. Assuming a 500 ohm (wet) body resistance arm-to-arm, the 200-volt case would produce 400 mA, somewhat below the 1000-mA threshold for inducing cardial fibrillation for a 10-ms exposure. Nevertheless, the potential of fibrillation is not absent at this exposure, and a fall from a ladder could easily result. When the grounding was rewired, the peak voltage was considerably reduced (right-hand graph).*

Even though programmatic work was restarted in all areas of TA-53 by the end of June 1999 (Figure 6), beam delivery to the Lujan Center could not be resumed for a variety of reasons that are discussed in Section 2.2, *Operation of the User Facility*.



▲ **FIGURE 6.** *Percentage of active programmatic work at TA-53 as a function of time after the February 5, 1999, safety stand down. The red curve indicates the restart schedule planned during the first few days of the stand down and the blue curve indicates actual work restarted.*

The LANSCE Division Director established a number of teams to provide advice on potential safety issues. The advisory teams and Chairs are listed in Table 3.

TABLE 3. *Advisory Teams Established for Potential Safety Issues.*

Team	Chair
Traffic Safety	Allen Jones (LANSCE-FM)
Communications Between Work Groups	Geoff Greene (LANSCE-DO)
User Facility Restart	Earl Hoffman (LANSCE-DO)
Experiment Safety	Steve Wender (LANSCE-3)
Shops, Cranes, and Forklifts	Troy Belyeu (LANSCE-FM)
Facility/Tenant Agreements	Jim Fraser (LANSCE-FM)
Notification and Lessons Learned	John Graham (LANSCE-FM)
Legacy Equipment	Bob Hardekopf (SNS)
Employee Safety Concerns	Chris Webster (LANSCE-9)
Student and Visitor Safety	Audrey Archuleta (LANSCE-DO)
Radioactive Materials Control	Jeff Bull (LANSCE-FM)
Paperwork Reduction	Dan Stout (SNS)
Root Causes and Systemic Issues	Rita Henins (ESH-7)

The reports from each of these teams resulted in important changes (some of which are listed below) in the way business is conducted at TA-53.

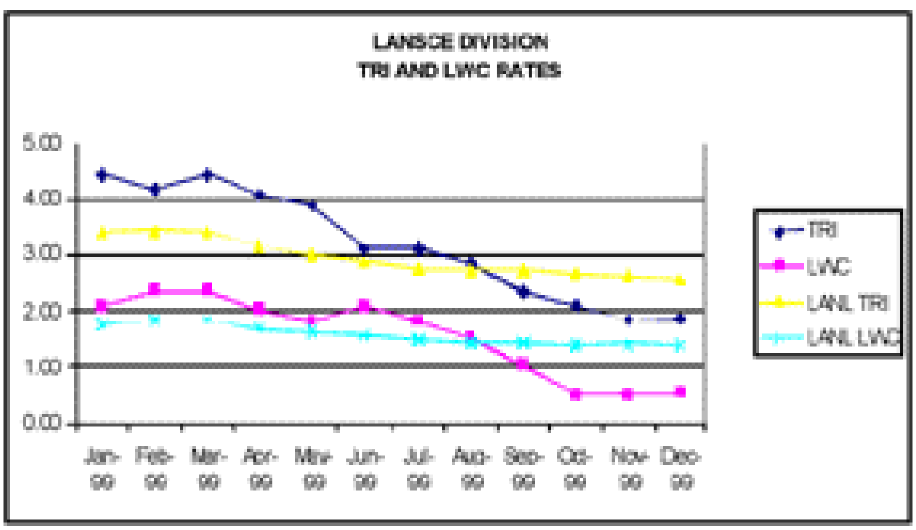
- A number of physical changes to roads, speed limits, pedestrian access, etc., were made to improve traffic safety (the employees' number one safety concern).
- Experimental Area Managers and Lead Tenants were appointed to improve work coordination and manage the overall safety envelope of various buildings and areas.
- Memorandums of understanding were written to define the roles and responsibilities of individuals and organizations, primarily within the User Facility.
- Experiment safety procedures for the User Facility were improved and rewritten, as were all TA-53 Facility/Tenant agreements.
- An Employee Safety Team was formed to provide ongoing suggestions for improvement and to ensure full future involvement of employees in TA-53 safety.
- Safety rules for shops, cranes, and forklifts were made consistent between LANSCE groups.
- New procedures were implemented for student and visitor safety.
- Legacy equipment left behind by previous programs at TA-53, some of it in an unknown configuration, was identified.

The Root Cause and Systemic Issues Team, chaired by an ESH Division Occurrence Investigator, identified three broad categories of issues that underlie reportable incidents over the past several years at TA-53. Table 4 lists assessments of those issues, which were taken verbatim from the team's report.

LANSCE Division has addressed each of the issues described in Table 4. A major cultural change was initiated to improve formality of operations, especially in relation to the operation of the Lujan Center spallation target, which is a Category 3 nuclear facility (see Section 2.2, *Operation of the User Facility*). A detailed assessment of the resources required to operate the User Facility had been prepared shortly before the safety stand down and is also described in Section 2.2. A plan for continuous improvement of Integrated Safety Management has been developed and was discussed in detail with auditors from the DOE's Office of Oversight during their audit of safety management at LANSCE in October 1999. As shown in Figure 7 below, the emphasis on safety has resulted in a significant decrease in lost work days and reportable incidents at LANSCE. It is management's assessment that continued attention to operational formality, as well as a significant increase in resources, will be required to achieve operational excellence.

TABLE 4. *Assessment of Issues Related to Reportable Incidents.*

Resources	"Current facility and infrastructure resources are not commensurate with existing expectations for facility operations, programmatic deliverables, and desired safety performance. Funding for the facility has failed to satisfy multiple and often conflicting demands to meet an expanded vision for the facility."
Culture of Informality	"An informal culture and lack of structure associated with R&D work processes was identified as a causal factor in the stand downs at TA-55, CMR, and TA-18. LANSCE/TA-53 has inherited a similar legacy from the time of the ER-sponsored nuclear physics program. This culture adversely affects effective communications, organizational interfaces, and clear understanding of roles and responsibilities. It should be pointed out that much of the effectiveness of LAMPF in the nuclear physics era was lost when the program ended and resources were significantly downsized."
Performance Assessment	"LANSCE currently has no formal process to routinely assess performance, capture and communicate lessons learned, or to proactively respond to situations that are statistically outside given control parameters. Meaningful data are available from occurrence reports, management walkarounds, safety concerns, and other sources but not evaluated outside the quarterly, Appendix F performance assessments."



▲ **FIGURE 7.** *Lost work day cases (LWC) and total reportable incidents (TRI) per 200,000 hours worked for LANL as a whole and for LANSCE during 1999. While the decreases are impressive, it is worth noting that current LANSCE values of TRI and LWC were achieved by "best-in-class" industrial companies over a decade ago. Current standards achieved by companies such as Exxon and Dupont are 1 and 0.5 for TRI and LWC, respectively.*

2 LANSCE User Facility

2 LANSCE USER FACILITY

2.1 Description of the User Facility

2.1.1 A National User Facility

LANSCE is the world's most versatile spallation neutron source. As a national facility for defense and civilian research in radiography, nuclear science, and condensed-matter science, LANSCE hosts scientists from universities, industry, the Laboratory, and other research facilities from around the world. LANSCE comprises a high-power, 800-MeV proton linear accelerator; a Proton Storage Ring (PSR); neutron production targets at the Lujan Center and the Weapons Neutron Research (WNR) facility; a proton radiography (PRAD) facility; a high-power materials irradiation area called the Los Alamos Spallation Radiation Effects Facility (LASREF); an isotope production facility (IPF); and a variety of spectrometers. With these capabilities, LANSCE supports a National User Program open to scientists from universities, industry, and federal laboratories.

Scientists may apply for beam time by completing a proposal, which is subjected to appropriate peer review before beam time is granted. Once beam time is granted, the experiment is reviewed for technical and safety issues. Information about LANSCE and a blank proposal form are available at http://lansce.lanl.gov/.

2.1.2 Particle Beam Production

2.1.2.1 High-Intensity Proton Linear Accelerator

The LANSCE high-intensity, 1–MW proton linear accelerator can simultaneously accelerate H^+ and H^- ions to energies of 800 MeV. The three-stage, half-mile-long linear accelerator provides H^+ beam with an average current of up to 1 mA at a repetition rate of 100 Hz and a peak of 17 mA. The H^- beam produced by the linear accelerator has an average current of up to 100 µA at a repetition rate of 20 Hz and a peak of 12 mA.

The first stage of the accelerator contains injector systems for each kind of particle (H^+ and H^-). Each injector system has a 750-keV Cockroft-Walton generator and an ion source. The particles leave their respective injectors at a velocity of 4% of the speed of light. The two ion beams are merged, bunched, and matched into a 201.25-MHz drift-tube linear accelerator for further acceleration to 100 MeV—43% of the speed of light. The third and longest stage of the accelerator (800 m) is the side-coupled-cavity linac; here particles are accelerated to their final energy of 800 MeV—84% of the speed of light.

The particle beams from the linear accelerator are separated and directed down three main beam lines that lead to several experimental areas, including Areas A, B, and C; the Lujan Center; and the WNR facility. Operators can control the H^+ and H^- beams separately so that most experiments can run simultaneously.

2.1.2.2 Proton Storage Ring (PSR)

The PSR converts H^- macropulses that are approximately 750 µs long into short (0.27 µs), intense proton (H^+) bursts that provide the capability for precise neutron time-of-flight measurements for a variety of experimental programs. H^- beam is converted to H^+ by removing its two electrons using a stripper foil in the injection section of the PSR. The injected proton beam has a substructure of several thousand micropulses produced by the acceleration process. The PSR collects these micropulses into one high-intensity pulse and ejects pulses toward the neutron target (located in the Lujan Center) twenty times a second.

2.1.2.3 Neutron Production

The spallation reaction occurs when protons strike heavy-metal targets such as tungsten and produce neutrons from the nuclei of the target atoms. For the 800-MeV proton beams used at LANSCE, about twenty neutrons per proton are ejected. The short, intense bursts of spallation neutrons are used in neutron-scattering and nuclear-science experiments.

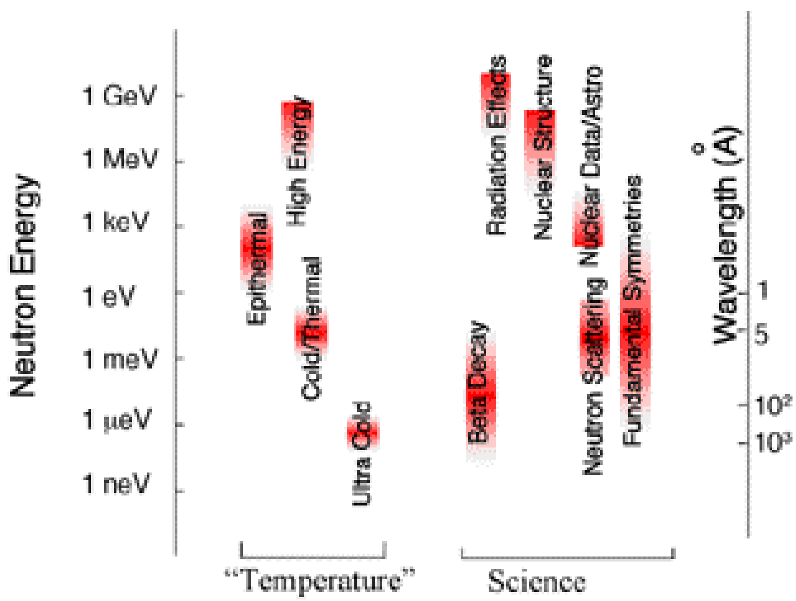
2.1.3 Experimental Facilities

2.1.3.1 Manuel Lujan Jr. Neutron Scattering Center

At the Lujan Center, moderated spallation neutrons are used for condensed-matter science and engineering and for nuclear-science research. Because of the unique design of the split tungsten target and its flux-trap moderators, the Lujan Center yields a higher peak neutron flux than any other spallation neutron source used for condensed-matter science and engineering. Of the sixteen flight paths, which currently provide seventeen independent neutron beams, seven have instruments for condensed-matter science and engineering, three are used for nuclear-science research, and the remainder are being instrumented (see Section 2.4.1, Short-Pulse Spallation Source Enhancement Project).

2.1.3.2 Weapons Neutron Research Facility

At the WNR facility, high-energy, unmoderated neutrons and protons are used for basic and applied research in nuclear science and weapons-related measurements. The WNR facility consists of two target areas: Target 2 and Target 4, and their associated flight paths. The neutron beams produced at WNR complement those produced at the Lujan Center because they are of much higher energy and have shorter pulse duration. With both capabilities, LANSCE is able to deliver neutrons with energies ranging from small fractions of an electron volt (thermal energies and colder) to 800 MeV (Figure 8).



▲ **FIGURE 8.** *LANSCE provides neutrons with energies spanning eighteen decades and can thus address a broad range of scientific problems.*

At Target 2, also known as the Blue Room, proton-induced reactions can be studied using the linear accelerator or the PSR proton beam. In addition, the Blue Room is used for a variety of proton irradiation experiments. This target is complemented by a low-background room with seven flight paths. Experiments in the Blue Room can exploit the variable-energy feature of the linear accelerator using proton beams from 250 to 800 MeV.

Target 4 is the most intense high-energy neutron source in the world. At this target, the proton beam from the linear accelerator is used to produce neutrons for the study of neutron-induced reactions. Target 4 consists of a "bare" unmoderated neutron-production target and six flight paths that have flight-path distances ranging from 10 to 90 m at angles of 15° to 90° with respect to the proton beam. The shape of the neutron spectrum ranges from a hard (high-energy) spectrum at 15° to a softer (low-energy) spectrum at 90°. The time structure of the proton beam can be modified for particular experiments.

2.1.3.3 Los Alamos Spallation Radiation Effects Facility

In response to the need for a complete understanding of radiation damage and corrosion phenomena at operating and proposed spallation sources, the Los Alamos Spallation Radiation Effects Facility (LASREF) offers a prototypical environment for testing materials for spallation environments at the 1-MW beam stop of the LANSCE linear accelerator. This capability was used during 1999 for materials-certification experiments in support of the APT project. The huge database that resulted from this activity is also important for the SNS that will be built at Oak Ridge National Laboratory (ORNL).

2.1.3.4 Proton Radiography (PRAD)

In Area C, scientists use H^- beam from the linear accelerator as a new radiographic probe for creating multiple high-resolution images of imploding or exploding objects on a submicrosecond time scale. Because protons interact with matter through strong electromagnetic forces, measurements of different material properties, such as material density and composition distributions, can be made simultaneously. In addition, protons have high penetrating power, can be detected efficiently, produce very little scattered background, and have an inherent multiple-pulse capability. Los Alamos scientists are developing PRAD as a tool for studying stockpile stewardship problems. They have developed magnetic optics; fast, integrating, large-area detectors; and containment vessels to lay the groundwork for advanced radiographic capability.

2.2 Operation of the User Facility

The Division's stated goal for calendar year 1999 was to operate the User Facility for six months. Specifically, we planned to deliver

- 3,240 hours to the Lujan Center;
- 747 hours to WNR Target 4;
- 440 hours to PRAD; and
- 480 hours for PSR development.

Once final budget allocations for FY99 were known (in January 1999), it became obvious that this goal could not be achieved. Given the magnitude of the shortfall, the only recourse seemed to be to curtail operation of one of the experimental areas. Planning for reduction of WNR operation was in progress when all beam operations were interrupted by a safety stand down ordered by LANSCE management on February 5, 1999, in response to several "near misses."

Following the stand down, linear accelerator operations restarted on May 27 with beam delivery to PRAD experiments in Area C. Shortly thereafter, beam delivery resumed on June 18 to WNR (see Figure 9).
Restart of both Area C and WNR occurred within one week of the schedule for these events that was developed shortly after the stand down. Although the same plan called for Lujan restart at the end of July, this was not achieved because both DOE and LANSCE discovered inadequacies in the Basis for Interim Operation (BIO) that had authorized operation in 1998. Required modifications to the 1998 BIO included:

- increase beam current to Lujan target from 100 μA to 150 μA;
- increase fraction of spallation target released during design-basis accident from 15% to 100%;
- use 95% weather rather than 50% weather to calculate dose consequences;
- correct dose conversion factors for various isotopes;
- include building heating, ventilation, and air conditioning (HVAC) system in accident analysis and add controls and monitoring for this system;
- include HVAC high-efficiency particulate air (HEPA) filter in loss-of-coolant accident (LOCA) analysis and its subsequent designation as safety significant for on-site worker protection;
- designate beam spill monitors as safety significant;
- consider possible rupture of flight path windows in the event of hydrogen detonation;
- consider LOCA in the reflector water system in the accident analysis;

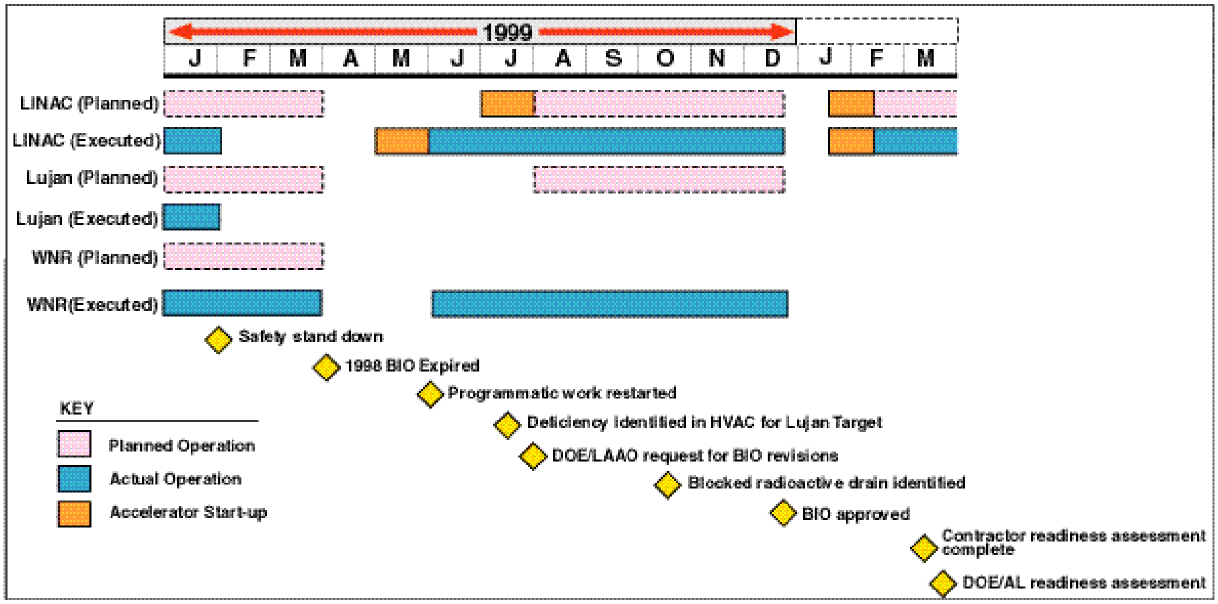


FIGURE 9. *Summary of planned and actual beam delivery during 1999 together with major milestones and other events. The planned beam time represents the goal established in January 1999 (see text).*

- consider target-crypt hydrogen fire in accident analysis; and
- perform additional analysis for earthquake and plane crash accidents.

On October 13, 1999, a contamination event associated with the Lujan spallation target reinforced two of the conclusions of the Root Cause and Systemic Issues Team chartered during the stand down (see Section 1.4, Safety Stand Down): predictable operational outcomes require a culture of formality, and legacies of past programs at LANSCE must be corrected if operational excellence is to be achieved. The October event required decontamination of ER-1 and the complete cleaning (snaking, flushing, and inspecting) of over 1,900 linear feet of radioactive liquid waste drains beneath the Lujan Center, the WNR, and the PSR (Figure 10).

In spite of their operational complexity, these tasks were completed in less than six months with one DOE-reportable occurrence and in full compliance with a complex web of environmental laws under the scrutiny of the New Mexico Environmental Department (NMED). Concurrently, LANSCE personnel developed over 50 new procedures (and revised many more) for operation of the Lujan spallation target to implement the required operational formality. Beam delivery and other events are summarized in Figure 9 and Table 5.

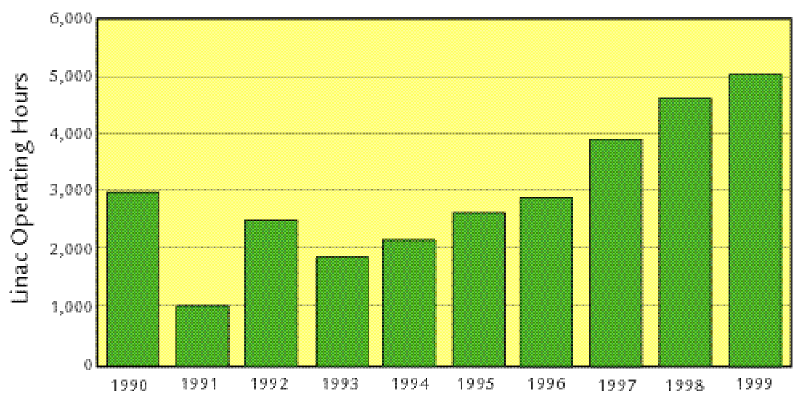
FIGURE 10. *Personnel working on vacuuming the radioactive liquid waste drain had to wear special protective equipment, including respirators.*

TABLE 5. Reliability of Beam-Delivery Equipment During FY99.

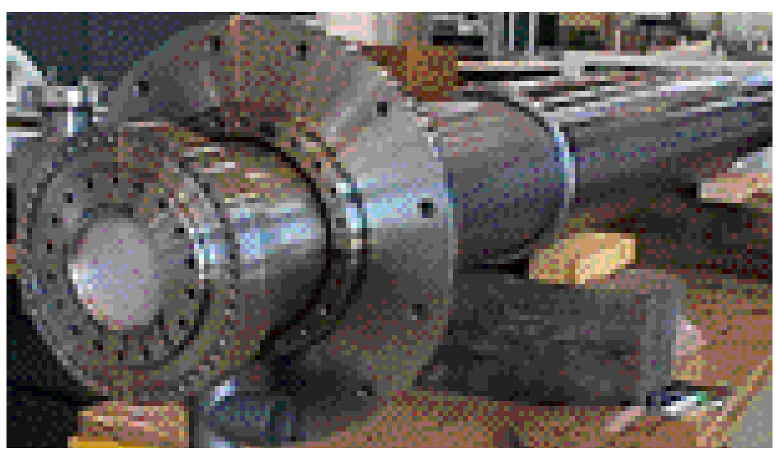
Facility	1999 Scheduled Beam* (hours)	1999 Delivered Beam (hours)	1999 Available Beam (%)
WNR Target 2	662	590	89%
WNR Target 4	2504	2005	80%
Lujan Center	312	240	77%
PRAD (Area C)	629	538	86%
PSR (Accelerator development)	480	547	--

* See text for definition of "scheduled hours" used in this table.

As shown in Figure 11, the linear accelerator operated well during the calendar year, setting a record for an operating period without shutdown for major maintenance (go to *http://lansce.lanl.gov/operation_DO/update11_99.htm* for more detail). The delay in restarting the Lujan Center allowed considerably more time to be devoted to researching the PSR instability (see Table 5 and Section 2.4.4, *Proton Storage Ring Upgrades*) than had been planned—to the great advantage of the SPSS Enhancement project. The delay also allowed four much-improved mercury beam shutters to be installed (Figure 12) at the Lujan Center without exposing the installation crews to levels of radiation that would have been seen with an extensively irradiated spallation target. Indeed, that job was completed with an accumulated dose of less than 300 mrem to the installation crews.

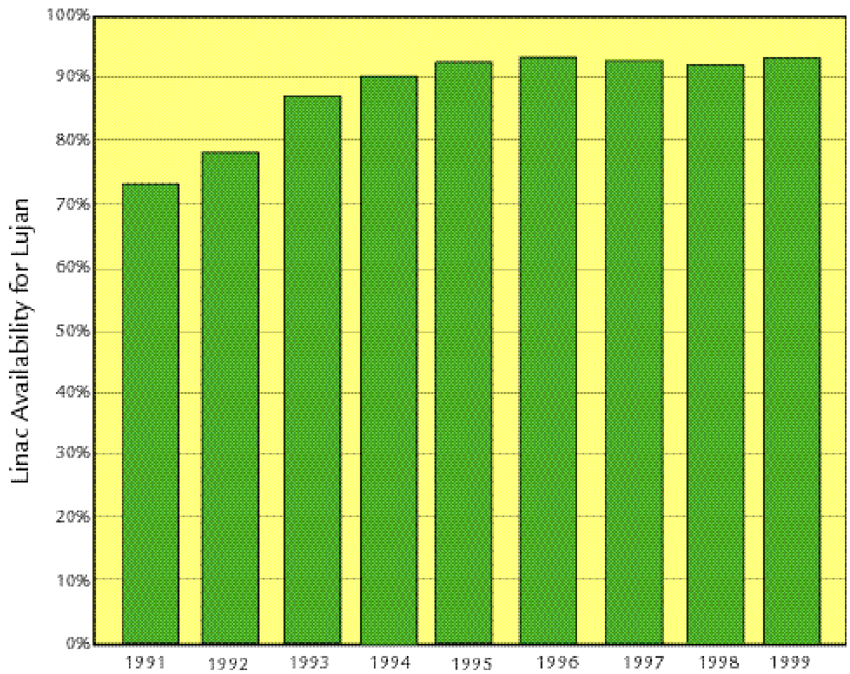


▲ **FIGURE 11**. *Number of hours of beam delivered by the linear accelerator by calendar*



▲ **FIGURE 12.** *This picture shows the pre-assembly of one of the mercury shutters being installed at the Lujan Center.*

Table 5 summarizes beam delivery to the Lujan Center and WNR during FY99. The number of scheduled hours does not include hours originally planned, which could not be delivered because events such as the safety stand down precluded beam delivery. Using this definition of scheduled hours, the overall beam availability at the Lujan Center (a measure of the reliability of the accelerator and target equipment) was approximately 77%.



▲ **FIGURE 13**. *Linear accelerator availability by calendar year.*

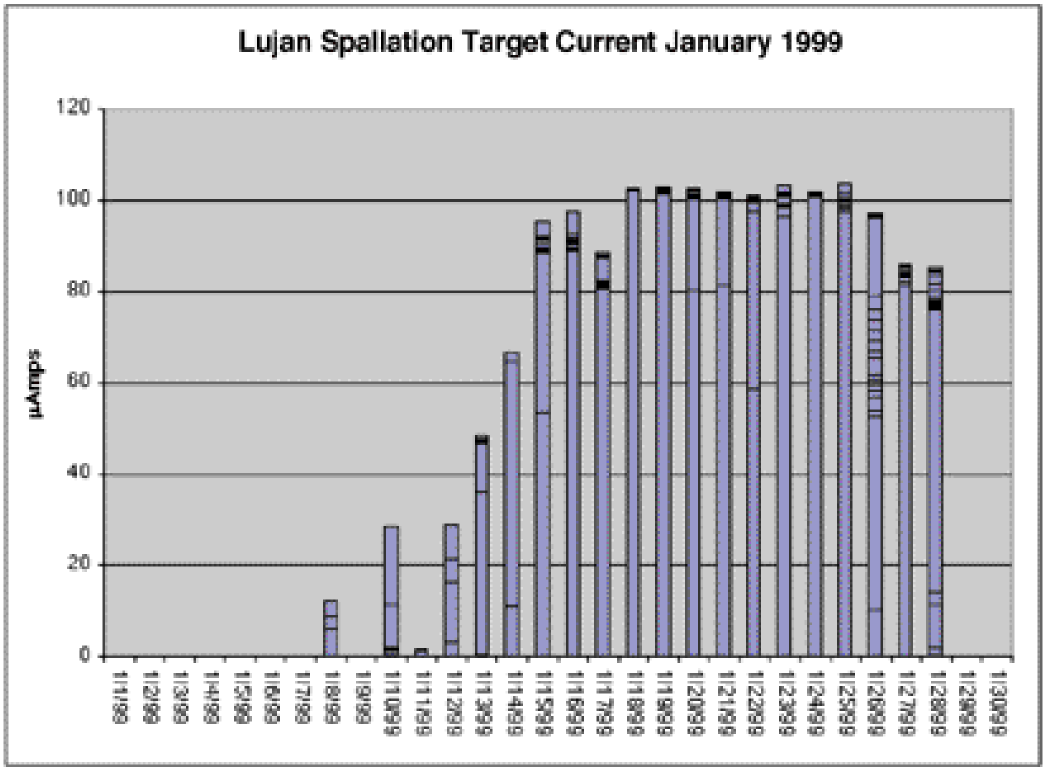
The contribution of the linear accelerator to this reliability (94%) is shown in Figure 13. Although equipment reliability did not meet the stated goal of 85% for beam to the Lujan Center, it is not unusual for availability to be below par during the first few weeks following accelerator turn-on.

During the limited operating period of the Lujan Center, beam delivery achieved a solid 100 µA (see Figure 14), demonstrating that the LANSCE Reliability Project had met its performance objective. Partly because they were not required to tune the linear accelerator for both H^+ and H^- beam, the operating crews were able to double the beam current to the WNR during the year (see Figure 15), allowing individual experiments to be completed more quickly and more users to be accommodated.

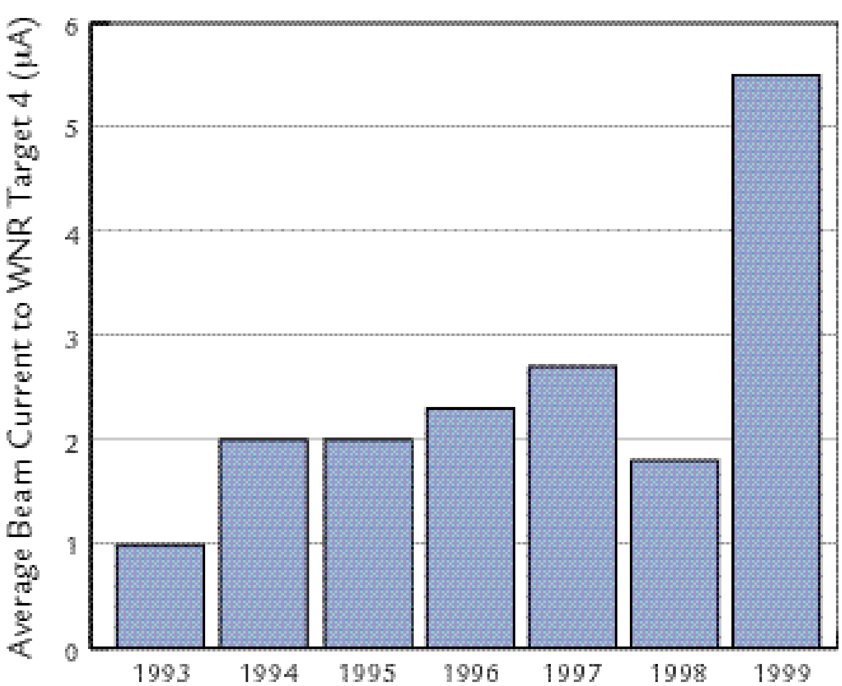
The record of successful dynamic PRAD shots continues to be impressive—of the 52 shots performed (as of March 15, 2000) since the invention of the technique, none have failed to receive beam as scheduled, although in one case (in 1997) a shot had to be repeated because the explosive failed to detonate at the first attempt (see Figure 16).

In conjunction with the safety stand down, a concerted effort was made to clean up and refurbish the PRAD facility. The delay line that had been installed for APT was taken down, and uneven surfaces on the floor were milled down for safety. Extraneous equipment not pertinent to PRAD was removed and stored elsewhere or salvaged. The Area C counting house was essentially gutted and refurbished. The refurbishment effort included replacing aging floor panels that had been identified as a safety hazard and recarpeting the area, removing countless legacy cables, rerouting and restringing current cabling, and installing furniture upgrades. This renovation was accomplished before PRAD received beam at the end of May 1999.

DOE authorization was required for the Billi G PRAD experiment (carried out in collaboration with UK scientists) because the high-explosive (HE) charge was about 150 g over the 750-g limit of the present authorization



▲ **FIGURE 14**. *An extract from the Lujan Center log for the period after accelerator was turned on in January 1999, showing daily delivery of 100 µA to the spallation target.*



▲ **FIGURE 15**. *Average proton current delivered to WNR Target 4 during each calendar year.*

basis. We undertook a hazards analysis to increase the load limit to 10 lb in Area C to cover Billi G, and we planned future experiments that require an increased HE load. A one-shot authorization for Billi G was obtained and the hazard analysis for the 10-lb limit is ongoing.

2.3 Noteworthy Scientific, Technical, and Programmatic Achievements

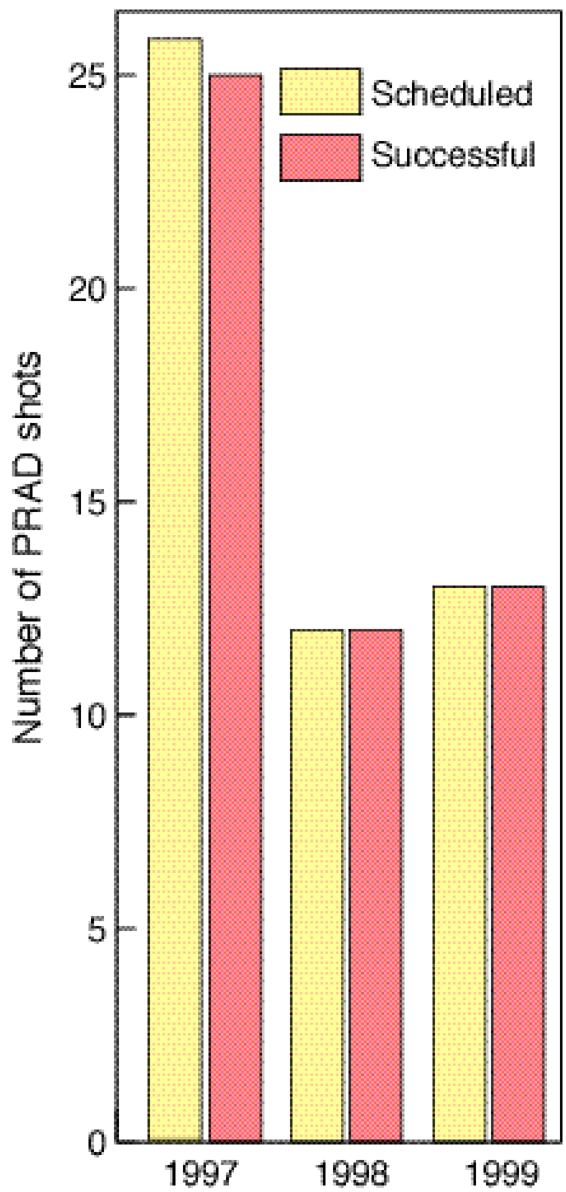
2.3.1 Neutron Scattering

2.3.1.1 Mn_{12} Clusters

High-spin molecules like Mn_{12} and Fe_8 currently are of great interest for two reasons. First, they can be considered model magnetic nanoparticles and are therefore relevant to magnetic-recording problems. Second, there is good evidence that the macroscopic magnetization tunnels quantum mechanically from one state (up) to the other (down), under certain field-temperature conditions. We have used both inelastic neutron scattering and neutron diffraction (both polarized and unpolarized) to study the magnetic excitations and the crystallographic and internal magnetic structures of the Mn_{12}-acetate molecule. These studies have allowed us to determine the magnetic Hamiltonian, a good low-temperature structure with all atom positions determined, and confirm a picture in which the inner four Mn_4^+ ions are polarized antiparallel to the outer ring of eight Mn_3^+ ions.

2.3.1.2 Asymmetric Magnetization Reversal in Exchange-Biased Bilayers

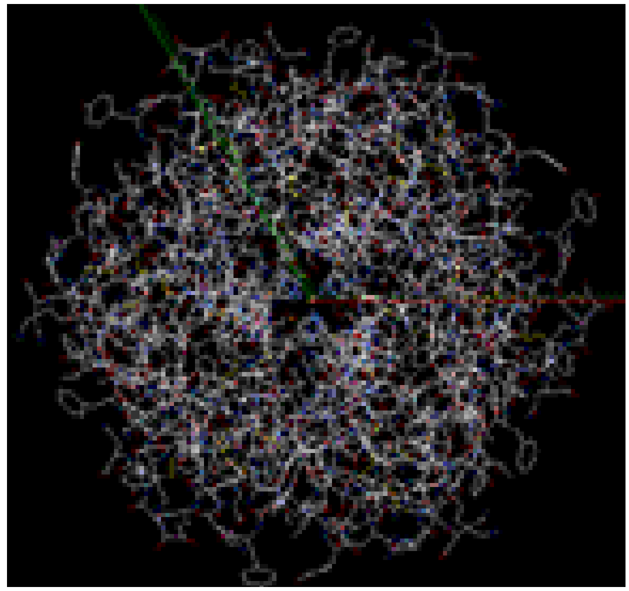
Exchange bias refers to an asymmetry of the ferromagnetic hysteresis loop about the zero applied field condition, $H_a = 0$. The exchange bias is a consequence of an interaction across an interface between dissimilarly ordered magnetic materials, e.g., a ferromagnet (FM) and an antiferromagnet (AFM). Even though the exchange bias between an FM and AFM is used in modern day recording media, a fundamental understanding of the phenomena is lacking. To test the number of theories explaining exchange bias, we have undertaken a comprehensive neutron study of a couple of model systems, e.g., Fe-FeF_2 and Fe-MnF_2. We have investigated the magnetization reversal process in these systems—two systems with very different magnetic anisotropy fields. We found that the reversal of the sample magnetization from one saturated state to the other occurred via either domain wall motion in the Fe film, or the rotation of the sample magnetization about the normal to the Fe-AFM interface plane. The mechanism whereby magnetization reversal occurred depended on the orientation of the cooling field and whether the applied field was increased to (or decreased from) a positive saturating field. The anisotropy fields of the AFM played little role, if any, in determining the reversal mechanism.



▲ **FIGURE 16**. *Number of dynamic Proton Radiography shots scheduled and successfully completed during each calendar year.*

2.3.1.3 Protein Powder Diffraction

We have demonstrated with real data the feasibility of refinement of protein crystal structures from powder-diffraction data. The results from refinement of the structures of three 800-1300 atom proteins from high-resolution synchrotron x-ray powder-diffraction data are essentially identical to the results obtained from single-crystal analysis on the same materials. The refinements were achieved by combining the diffraction data with a suite of stereochemical restraints (bond lengths, bond angles, torsion angles, planar groups, chiral centers, etc.) in a modified least-squares procedure embodied in the General Structure Analysis System (GSAS). There were also parallel developments in the visualization and characterization of the results of these refinements. Most recently we have uncovered a new structural modification of one of these proteins and have now determined its crystal structure from the powder diffraction data (see Figure 17).



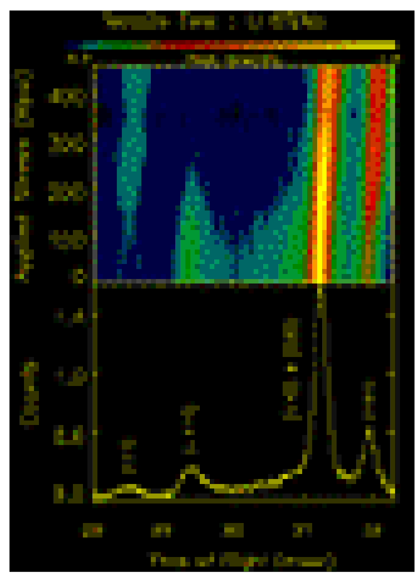
▲ **FIGURE 17**. *The R3 structure of Zn insulin consisting of 1600 atoms in a unit cell.*

2.3.1.4 Preferred Orientation in Mn_2GeO_4

It is well known that preferred orientation of the dominant upper-mantle mineral in the Earth α-olivine is expressed in seismic anisotropy of the upper mantle. The contrast in seismic wave velocity at the upper seismic discontinuity (410 km) could be induced by different lattice preferred orientations (texture) between α- and β-olivines that undergo dislocation creep. We investigated preferred crystallographic orientation development in transformed and deformed experimental polycrystalline specimens of both the α- and β- phases of Mn_2GeO_4 and α- and γ- phases of Mg_2GeO_4 by neutron diffraction. In particular in Mg_2GeO_4 material, we found (100)α // (001)β // maximum compression; (010)α // (100)β and (001)α // (010)β perpendicular to compression. In Mg_2GeO_4 material, we found (100)α // maximum compression with all ring-woodite structures (γ) nearly randomly oriented. The work is interesting especially because it reproduces in the laboratory the anomalous behavior of older generation olivine orientation observed in the Alpe Arami (go to *http://lansce.lanl.gov/research/cond-matter/bennett.htm* for related information).

2.3.1.5 Deformation Mechanism of Uranium 6 Weight % Niobium Alloy

U6Nb (15.4 atomic %) is currently an alloy of interest to the Stockpile Stewardship Program at Los Alamos. To date, its deformation mechanisms are not well understood. Attempts at modeling the mechanical behavior of the alloy using existing constitutive models have been unsuccessful because of the atypical response of the alloy to mechanical stress. The U6Nb alloy deforms in a linear elastic manner to roughly 125 MPa. Above 125 MPa, however, there is a stress plateau in the stress-strain curve, after which the work hardening again increases. Using time-of-flight neutron diffraction, we have characterized both the lattice parameters and the grain orientation of a U6Nb sample under applied tension (see Figure 18). These studies indicate that the plateau in the stress/strain curve may be attributed to deformation twinning. The deformation of U6Nb is still a work in progress, however. A



▲ **FIGURE 18**. *Contour plot of the neutron diffraction data of U6 weight% Nb under load. The changes in peak intensities with stress indicate twinning is present. There is no evidence of new diffraction peaks to indicate a phase change.*

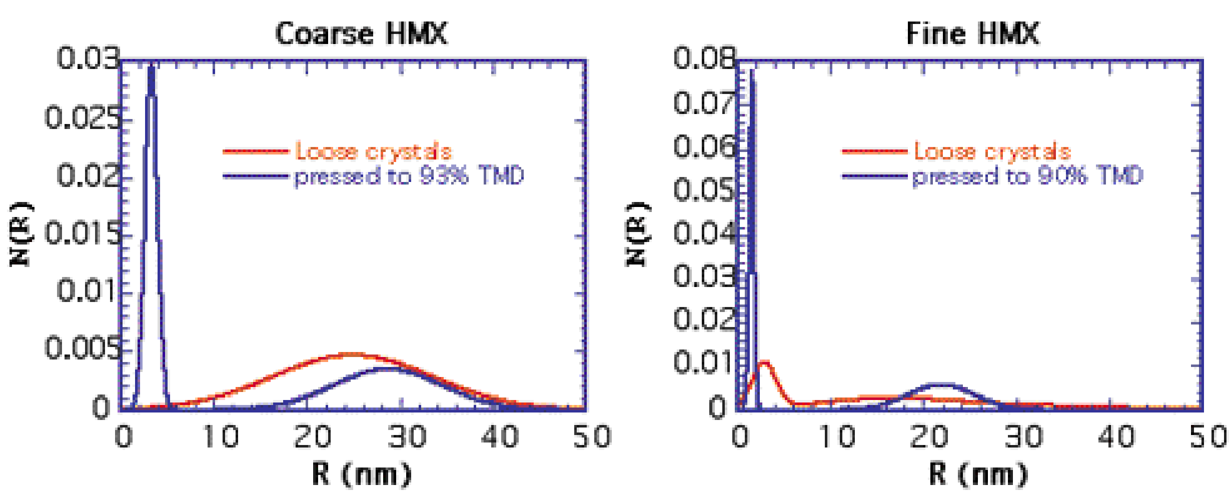
physically correct model will only emerge with the complete understanding of the twin system—that is, by determining the twin plane(s) and resolving shear stress at which twinning becomes active. To accomplish these tasks, we are analyzing data already collected and conducting more experiments. Visit *http://lansce.lanl.gov/research/cond-matter/brown.htm* for more information on this subject.

2.3.1.6 Nanostructure of High Explosives

We used small-angle neutron scattering (SANS) to probe the structure of HE. We measured external surface area per gram and internal void size distributions in HE crystallites and the changes that occur as a result of process-related mechanical insult. We worked on the structure of the polyurethane binders in PBX9501, assessing the morphology of hard and soft segment domains and the changes that occur with ester hydrolysis. We also did work on the distribution of plasticizers in the binders.

By immersing the sample in a uniform fluid of known neutron-scattering length density, which changes the contrast of the crystals against the background, we can distinguish the inside of the HE crystallites from the outside. SANS measurements, using this method of contrast variation, were done on the HE, tetranitro tetrazacyclo-octane (HMX), in both fine and coarse crystalline powders and in pressed pellets. Detailed analysis showed that the external surface area per gram is larger in fine versus coarse crystalline powders and that the fabrication of pellets by pressing has little or no effect on the measured surface area. The analysis also showed that fine material had considerably smaller internal voids than did coarse material and that pressing reduced the mean size of both to about the same absolute value (Figure 19).

On hydrolysis of the ester bonds, the predominant mechanism of Estane aging, a peak at Q = 0.04 Å^{-1} moves to progressively higher Q-values. This observation indicates that the spacing of Estane hard segments becomes more densely packed on hydrolysis. Measurements using deuterated and protonated plasticizers suggest that the plasticizer is associated with the soft segments. The website *http://lansce.lanl.gov/research/cond-matter/mang.htm* has more information on this topic.



▲ **FIGURE 19**. *High-explosive HMX: coarse (left) and fine (right) samples, both as loose powders and pressed, show differences in pore size distribution.*

2.3.1.7 Plasticizer Behavior in Thin Polymer Films

We have studied the behavior of a two-component polymeric system, estane and plasticizer. Estane is a block copolymer with alternating blocks of hard and soft segments. Thin films approximately 600Å thick were prepared by spin coating the polymer onto a silicon wafer from dichloroethane. The neutron reflectivity of the sample was measured and then the sample was annealed at 80°C for lengths of time varying from 5 minutes to

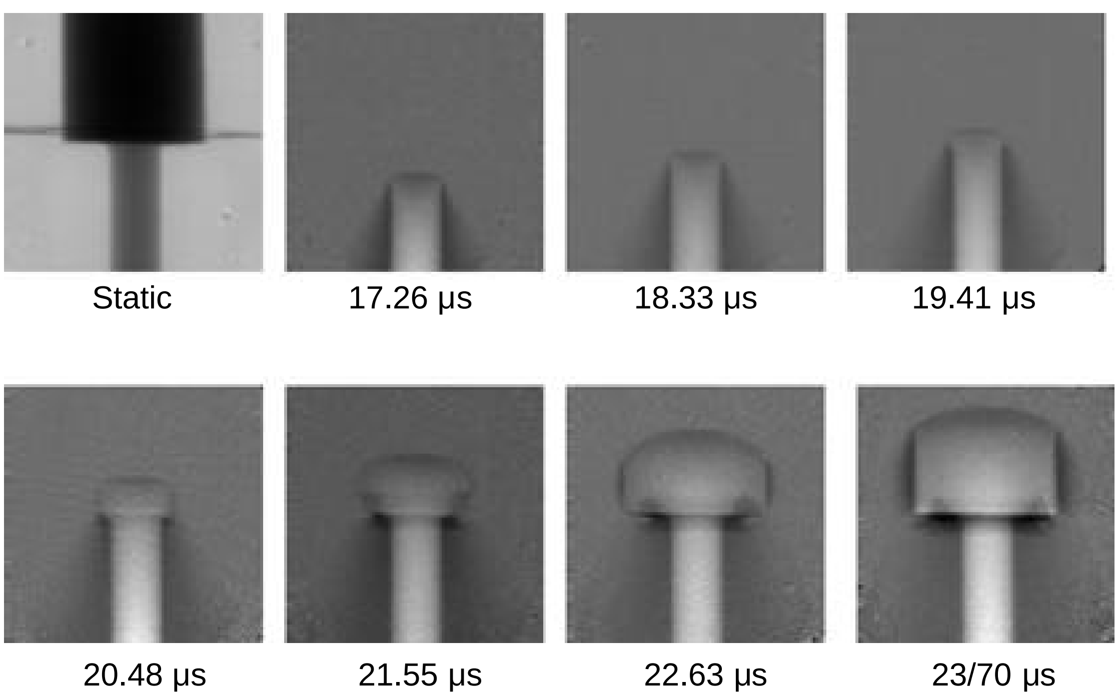
3 days. The samples were quenched to room temperature after each anneal. The neutron reflectivity was then measured. The analysis of the data shows that the unannealed sample was composed of a thick layer next to the silicon and a thin layer at the air surface. The density of the thick layer corresponded to a 50/50 weight % mixture of estane and plasticizer as prepared. The thin layer of higher scattering length density found at the air/polymer surface is consistent with surface-segregated hard segments of the polymer chain. As a function of annealing time, the film thins and the scattering length density of the major portion changes from the 50/50 mix toward that of pure estane polymer. This indicates diffusion of the plasticizer from the film. For each anneal, the approximately 30-Å-thick thin layer is found at the air interface. The most surprising aspect of the data is the fact that a Fickian density profile for the diffusion of the plasticizer cannot be fit to the data, and in fact the major portion of the film is fit with a single flat layer. This finding implies a two-step process where the plasticizer is released slowly from the polymer; but after release, its transport through the film is very rapid.

2.3.2 Radiography

2.3.2.1 Proton Radiography Achievements

Area C at LANSCE provides the weapons program with a state-of-the-art PRAD capability at 800 MeV. The PRAD program in Area C, conducted primarily by scientists from the Laboratory's Physics Division, has three thrust areas: (1) performing dynamic experiments or shots that meet the data needs of the weapons program; (2) developing technology for better PRAD; and (3) providing a test bed for technology that will be required for an Advanced Hydrotest Facility (AHF).

In calendar year 1999, the PRAD team performed twelve dynamic shots, which fell into three classes: outside user experiments, HE dynamic studies, and implosion dynamic studies. For outside user experiments, we hosted personnel from Sandia National Laboratories (SNL) for three shots that investigated the functioning of voltage bars. The HE dynamic shots included further studies of hockey pucks and other geometries to continue our investigation into the formation of dead zones in high explosives. One specific experiment performed—the Cambell-Cox

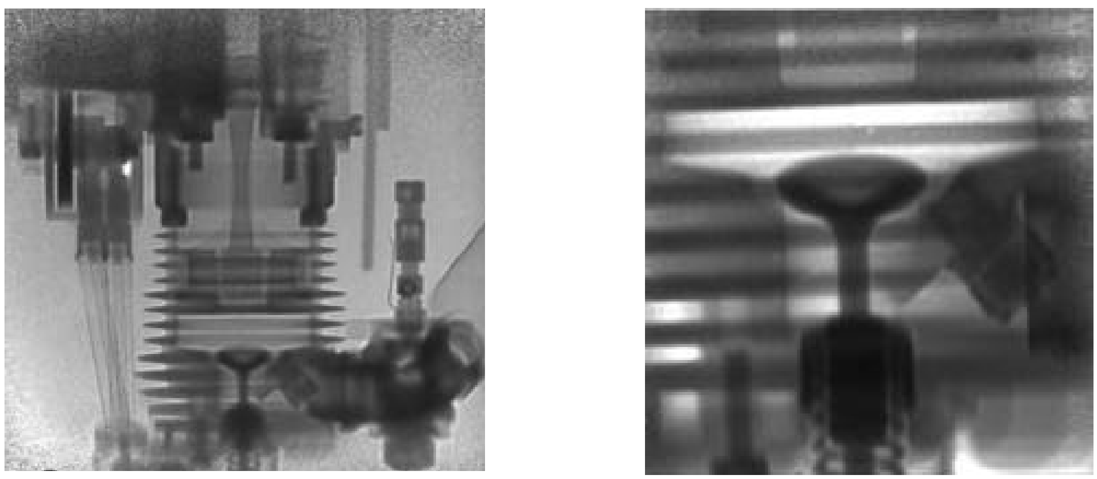


▲ **FIGURE 20**. *Reduced data from a "corner-turner" experiment taken October 21, 1999, showing how the HE detonation runs from a narrow cylinder into a larger cylinder having to "turn the corner." Unburned HE can be seen as dark regions (dead zones) at the edge of the large cylinder beginning in the sixth frame (at 21.55 µs).*

"corner-turner" experiment—detonated a small cylinder of HE into a larger cylinder (see Figure 20). Dead zones are clearly visible as the detonation tried to "turn the corner" to the outside of the larger cylinder.

This year saw the first attempt to look at implosion dynamics with the experiment dubbed Billi G. Billi G was a very successful collaboration with our Aldermaston Weapons Establishment (AWE) colleagues from Britain. The Billi G experiment required the joint efforts of LANSCE, P, X, ESA, ESH, and DX Division personnel. An eleven-frame movie of the implosion was obtained. This radiographic sequence, which captured more than two frames of an implosion, was the first of its kind ever obtained anywhere in the world (see *http://lansce.lanl.gov/news/features/990909_billig.htm*).

The image quality and size that is possible with PRAD is very dependent on the magnetic lens system. Reconfiguring the power supplies of the existing magnets in Area C allowed us to achieve a magnification of three without having to move any magnets or purchasing new power supplies. Under the auspices of LDRD, the power supplies were rewired and a "x3" magnification of an image was successfully demonstrated (Figure 21). We have since done calculations that indicate that it is possible to achieve "x9" magnification in the future in Area C.



▲ **FIGURE 21**. *Images of a model airplane engine taken in the normal mode (left) and with the new "x3" magnifier (right) in Area C. Internal details are clearly visible.*

To fully capitalize on the multi-timeframe nature of PRAD, the team has developed new detector schemes. During 1999, a 8 x 8 pixel array was tested in Area C as a concept prototype for a "mega"-pixel detector that could be used in an Advanced Hydrodynamic Facility (AHF). The array was tested using both ion chamber and photodiode array readouts. The results were very encouraging.

Area C received approximately 540 hours of beam during FY99. Beam was used for setup, calibration, technology demonstrations, and dynamic shots. A total of twelve dynamic shots were performed.

2.3.2.2 Fast Neutron Radiography

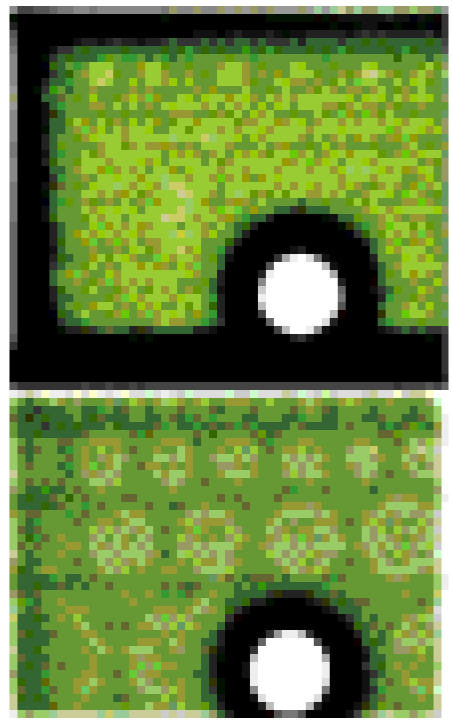
The WNR Target 4 spallation neutron source produces a broad spectrum of neutrons ranging in energy from sub-MeV to several hundred MeV. This source is therefore well suited for testing and developing a variety of neutron imaging and surveillance techniques that can then be applied to the design of neutron sources optimized for specific applications. These future sources may include a high-intensity facility at Line A (where the current can be over two orders of magnitude greater than that possible at WNR) or compact and portable facilities for californium or deuterium-tritium (DT) sources.

A comprehensive effort was carried out on WNR flight path 4FP30LB to develop high-energy neutron-radiography techniques capable of addressing urgent stockpile stewardship issues. The main thrust of these efforts was to define the mass sensitivity (contrast), spatial resolution, and count-rate capabilities of existing neutron-imaging techniques and to identify problems requiring further research and development. The ultimate goal is to assemble a system capable of doing tomographic imaging on extended dense objects with both good spatial and density resolution.

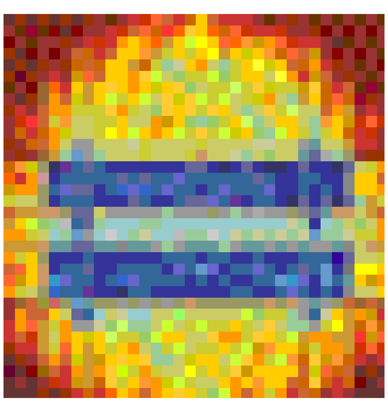
Measurements were carried out at a flight path of 40 m from Target 4. At this distance, the finite target size yields spatial resolution in the 0.5- to 1-mm range for 0.5- to 1-m object-to-detector separations. Collimators in the beam line were opened up to produce a 20-cm-diam beam spot at the object location. With 5 μA of proton current incident on Target 4, the neutron flux at this location is approximately 10^6 n/s/cm^2 integrated over neutron energies from 1 to 800 MeV.

Two imaging systems were tested: storage-phosphor image plates and amorphous silicon panel detectors. The storage-phosphor plates have a wide dynamic range (10^5) and can be used for exposures ranging from several minutes to many hours. Images are developed by scanning the exposed plates with a laser scanner with selectable resolutions ranging from 75 to 600 dpi (338 to 42 μm). The amorphous silicon panels are limited by dark-current buildup to integration times of several minutes but have the advantage of electronic readout without physically disturbing the detector. For short exposures, results from the two imaging systems were very similar.

Mass-sensitivity (contrast) measurements were carried out using a variety of thin sheets sandwiched between flat metal plates. We successfully detected holes in 20-mil Mylar sheets (75 mg/cm^2) and 30-mil plastic drafting templates (96 mg/cm^2) sandwiched between 3/4-in. iron plates; layers of aluminum, lead, and iron; and 2-in.-thick uranium cubes. Figure 22 shows results using 3/4-in. iron plates.



▲ **FIGURE 22**. *Image of detected holes in 20-mil Mylar sheets (75 mg/cm^2) and 30-mil plastic drafting templates (96 mg/cm^2) sandwiched between 3/4-in. iron plates.*



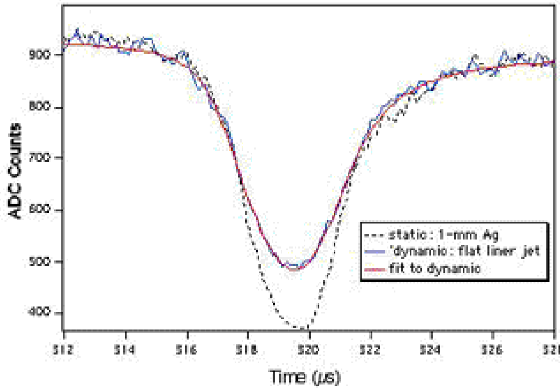
▲ **FIGURE 23**. *A tomographic reconstruction from twelve views of two iron plates separated by a 1/2-in. gap.*

Figure 23 is a tomographic reconstruction from twelve views of two iron plates separated by a 1/2-in. gap. The reconstructed image is a cross section through two bolts holding the plates together. Future efforts will extend the number of views by an order of magnitude and should be capable of detecting holes in thin plastic layers similar to those in Figure 22.

2.3.3 Nuclear Science

2.3.3.1 Neutron Resonance Spectroscopy

In 1999, users from the Laboratory's DX Division successfully measured the temperature and thickness of three explosively driven silver jets (Figure 24), one formed from a flat liner and two formed from tapered liners using neutron resonance spectroscopy (NRS). NRS is a technique in which a temperature is determined by measuring the Doppler broadening of a low-energy neutron capture resonance. As part of the silver-jet experiment, they also performed measurements during two additional jet



Shot	T (deg K)	thickness (mm)
Flat Liner	875	0.49
Tapered #1	816	0.86
Tapered #2	1050	0.63

▲ **FIGURE 24**. *Measurement of temperature in one flat-liner and two tapered-liner jet shots.*

firings, whic were designed to be analysis aids. To better analyze NRS data, the experimenters developed an algorithm for calculating the effects of an energy-dependent moderator time dispersion on the observed line-shape.

In parallel to the silver-jet shots, dynamic NRS measurements were made of the temperature behind a shock in a shocked molybdenum sample. In these shocked-metal shots, the experimenters initiated the HE-driven propulsion of their flyer plate with a plane-wave lens rather than with the multipoint system used in the past. Because of the increased amount of HE needed for the new method, we had to transition from a 1-m to a 1.3-m containment vessel. In 1999, NRS successfully proofed and then safely fired three NRS shots at LANSCE in the larger 1.3-m vessel.

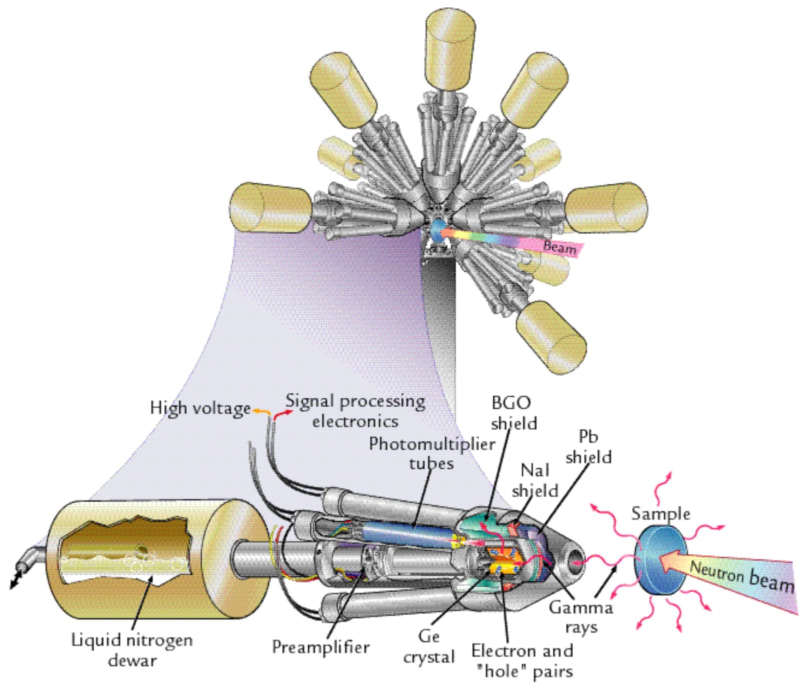
DX scientists also made preparatory static NRS measurements on test assemblies designed to provide information relevant to three future experiments. These experiments will measure temperature at the frictional interface of dissimilar metals, complement proton radiography experiments in the study of dead zones in HE, and measure temperatures in the reaction zone of detonating HE. More information can be found at *http://lansce.lanl.gov/research/nuclear/yuan.htm*.

2.3.3.2 Germanium Array for Neutron-Induced Excitations

In FY99, data were taken on ^{239}Pu, ^{238}U, and ^{235}U with the GEANIE detector array (Figure 25) to complete data acquisition for (n,2n) excitation function measurements for the nuclear weapons program. A new development in this effort was the use of very thin Fe foils to allow cross-section determinations relative to the strong 847-keV line in ^{56}Fe(n,n$\rightarrow\gamma$). In addition, the strong lines in Cr, V, Al, and Si were measured relative to Fe. These data will allow us to improve the knowledge of these cross sections that serve as standards for calibrations and measurements. The improvements in beam delivery to WNR was crucial in obtaining the present results.

Refined measurements of sample thickness and the fission foil thickness (used to determine the neutron fluence) are being pursued, along with reduction of the new data, to obtain accurate partial cross-section values from the experiment. For the 103-keV and 158-keV transitions, good agreement is obtained with GNASH calculations for which no adjustments have been made to match the data.

To improve nuclear-reaction models and Accelerator-Driven Transmutation of Waste (ATW) applications, we measured ^{209}Bi with GEANIE to determine (n,xn) cross sections. Bi(n,xn) cross sections can be used as a diagnostic tool in measuring the neutron flux as a function of energy and to improve the calculation of the neutron production. As part of a program of fission studies, we obtained good results testing the deposit of fragments of thin ^{238}U foils on Si cells in the neutron beam. Future measurements will allow us to develop detailed



▲ **FIGURE 25**. *Cutaway view of GEANIE. Gamma rays produced from reactions in the target enter the detectors and, by a series of interactions, deposit their energy in the germanium (Ge) crystals. An electric signal proportional to the energy deposited is created in the Ge crystal and then amplified and digitized. The distinguishing characteristic of the Ge detector is its excellent gamma-ray energy resolution. Events in which some energy is lost from the Ge crystal are detected in the bismuth germinate (BGO) and sodium iodide (NaI) scintillator shields. Rejection of these events reduces unwanted background in the gamma-ray energy spectra obtained from the Ge detectors.*

mapping of the mass distribution of fission fragments as a function of incident neutron energy. Upgrades of the analog-to-digital converters and spectroscopy amplifiers this year resulted in improved resolution and stability and increased data-acquisition-system throughput that benefited all of the experiments. Go to *http://lansce.lanl.gov/research/pdf/nelson_GEANIE.pdf* for more information on GEANIE.

2.3.3.3 Few-Body Nuclear Interactions

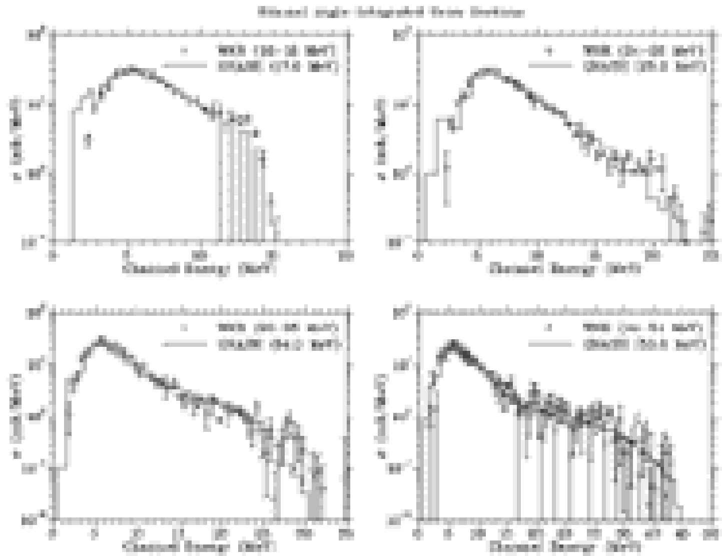
The study of few-body nuclear systems is a very active field of nuclear physics research. Such systems are simple enough to test the underlying physics assumptions without introducing the large calculational uncertainties associated with complex nuclei. We have, for several years, been systematically addressing several issues in the physics of neutron-proton reactions. The high-energy neutron beams at the WNR facility provide the only way of accessing these reactions, since neutron targets do not exist.

An experiment to measure the differential cross section for neutron-proton bremsstrahlung (NPB) has been completed during the last run cycle. NPB is an inelastic n-p scattering phenomenon. Data have been acquired in the neutron energy range from 100 to 600 MeV by observing neutron-proton coincidences. The data, which are currently being analyzed, are the topic of Y. Safkan's Ph.D. thesis. Along with the NPB results, the data set contains information on higher energy inelastic channels such as $np \rightarrow pp\pi^-$ and $np \rightarrow np\pi^0$.

During the upcoming run cycle, we will perform an absolute measurement of the cross section for neutron-deuteron elastic scattering in the energy range from 100 to 300 MeV. Recent Faddeev calculations exhibit sensitivity to three-nucleon forces in this energy region. The existing proton-deuteron scattering data disagree with the theoretical predictions. There are as yet no data on the neutron-deuteron scattering cross section.

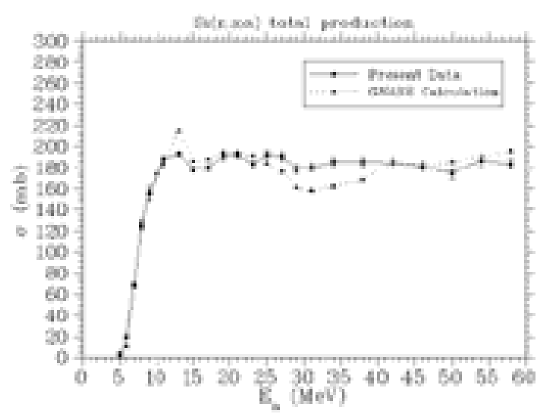
2.3.3.4 Level-Density Information for Nuclear Reaction Models

We have been studying nuclear level densities with several different approaches at WNR. Our most recent study has been in the region around silicon where we measured charged-particle emission following neutron bombardment of natural silicon. A sample of the extensive data (Figure 26) shows that the alpha particle emission spectrum is dominated by evaporation from the compound nucleus to give the large peak around 6 MeV. The shape of the emission spectrum and the agreement with the calculation via the LANL code GNASH shows that our knowledge of the level density is rather good in this case. But this agreement on a logarithmic scale can be deceptive. A more stringent test is how well the cross section is calculated after these emission spectra are integrated (Figure 27). Here again the agreement is good, showing that not only do we know the shape of the level densities but also the relative level densities for the competing channels. On further analysis, we uncovered that another ingredient—isospin—must be put into the calculations so that the proton and neutron content can be considered explicitly. The inclusion of isospin makes a significant difference in the calculations, about 30% in this case (Figure 28); not including it means that perhaps we don't know the relative level densities in the competing channels as well as we originally thought.

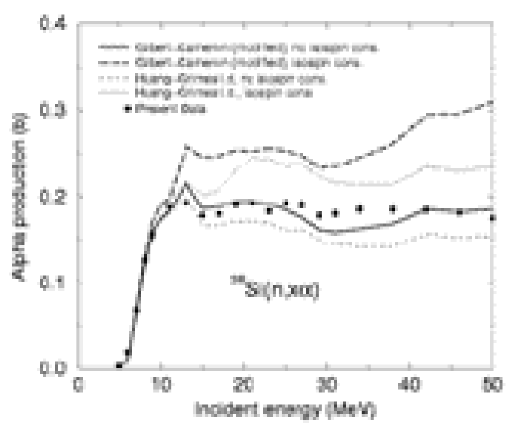


▲ **FIGURE 26**. *Angle-integrated spectra for alpha particles emitted from silicon bombarded with neutrons of energies 16–18 MeV, 24–26 MeV, 33–35 MeV, and 49–51 MeV.*

These phenomena in silicon have attracted much attention from the electronics community because neutrons can cause "single-event upsets" in computer chips. A single-event upset is an event in which one bit in a computer or memory chip is changed from a 1 to 0 or vice versa. Reaction studies on oxygen and calcium are also of considerable interest. This data will be of great interest to the medical community as well for considerations of neutron cancer therapy and the biological effects of radiation. The medical community needs these basic data to interpret the effects of neutrons on biological materials. The possibility of making these measurements over a wide range of neutron energies simultaneously is unique to the WNR facility because of its high neutron



▲ **FIGURE 27**. *Alpha particle production for neutrons up to 60 MeV. The GNASH calculation agrees reasonably well with our data.*

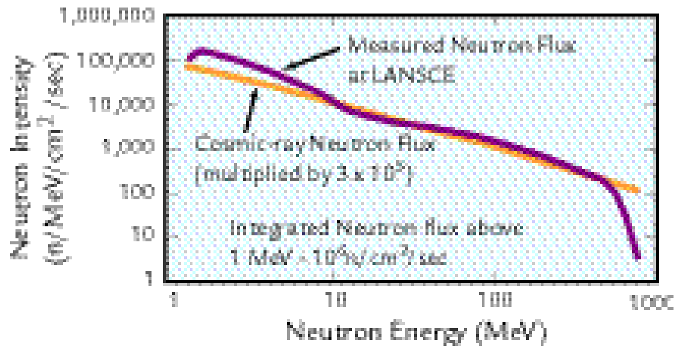


▲ **FIGURE 28**. *Alpha-particle data compared with calculations using two level density formulas to show the effects of isospin.*

intensity throughout this energy range. Visit *http://lansce.lanl.gov/research/pdf/wender1_00.pdf* for related information on this subject and other activities being conducted at WNR.

2.3.3.5 Single-Event Upset Studies

Neutron-induced failure in semiconductor parts and systems are an emerging concern for the aerospace and consumer electronics industry. Because of their long mean-free paths, neutrons that are produced in the upper atmosphere by cosmic rays can reach aircraft altitudes and below. Cosmic-ray-induced neutrons are thought to be the major source of radiation-induced upsets at aircraft attitudes. When these neutrons interact with the material in the semiconductor part, they can produce charged recoils, which can deposit charge or drain charge from the storage nodes, which causes the stored information to change. In addition other failures, such as latch-up, gate rupture, etc., can cause even more severe damage. The neutron beam at the WNR has a spectrum that is very similar to the cosmic-ray-induced neutron spectrum (see Figure 29). Because the intensity of the WNR beam is 10^6 times greater than the cosmic-ray flux, semiconductor parts may be tested at a greatly accelerated rate. One hour of beam time at WNR is equivalent to over 100 years of experience. Since the first experiments on neutron-induced upsets were performed by the Boeing Company in 1992, over 30 User Facility Agreements have been made with over 15 different companies to study the effects of neutron radiation. During the past run cycle researchers from Intel Corporation, Altera Corporation, Saab Aerospace, and the NASA Center for Applied Radiation Research (CARR) used the WNR beam. Go to *http://lansce.lanl.gov/research/cond-matter/wender.htm* for more information.



▲ **FIGURE 29**. *Neutron flux at WNR compared to the cosmic-ray-induced neutron flux.*

2.4 Current User-Facility Upgrade Projects

2.4.1 Short-Pulse Spallation Source (SPSS) Enhancement Project

The dual goals of the SPSS Enhancement project are
- to increase the Lujan Center neutron source intensity by delivering more proton beam power to the neutron-production target and
- to increase the technical capabilities of Lujan Center by constructing five additional state-of-the-art neutron scattering spectrometers.

Achieving these goals will increase the experimental capabilities of the Lujan Center by approximately a factor of four by doubling the neutrons available and doubling the instrumentation that uses the neutrons. The DOE Offices of Defense Programs (DP) and Science (SC) jointly support the overall SPSS project. DP is funding the Accelerator Enhancement project, and SC is funding the Spectrometer Development project.

2.4.1.1 Accelerator Enhancement

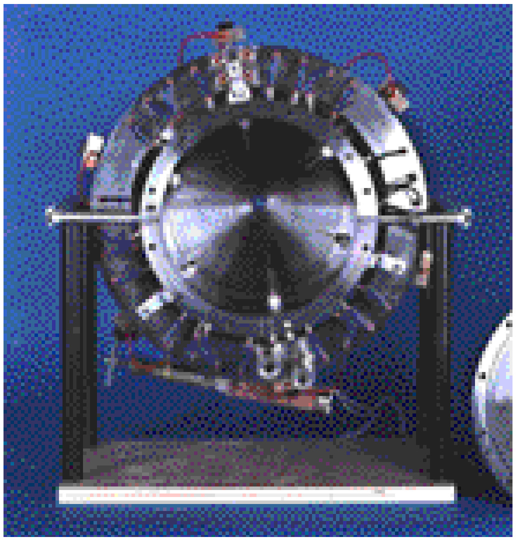
The primary technical goal of the upgrade to increase the average proton current delivered to the Lujan Center spallation target to 200 µA at a 30-Hz repetition rate to provide 160 kW of power to the target. To achieve this performance goal, the following major modifications to the LANSCE accelerator facilities are being carried out:

- A brighter H^- ion source for the accelerator is being developed in collaboration with Lawrence Berkeley National Laboratory (LBNL), and the accelerator injector's 80-kV accelerating column and low-energy beam transport system are being modified to accommodate the new source.

- The PSR is being upgraded to handle higher accumulated charge levels. The upgrade includes a redesigned rf buncher, which will provide higher bunching voltage and greater reliability, and modifications to the ring to control PSR instability and to minimize slow beam losses.

Ion Source and Injector Development. The LANL/LBNL collaborative development and construction of the new ion source and injector improvements comprise the following major elements:

- Development and fabrication of axial proof-of-principle, prototype, and final production sources at LBNL. The technical goal for the source is 20-40 mA. Both prototypes have been developed and tested. The final production source has been designed and two sources have been fabricated (Figure 30).
- Construction, instrumentation, and validation of the ion source test stand (ISTS) at LANL. (The ISTS has been completed.)
- Redesign of the injector's 80-kV column to accommodate higher source current. (The column redesign has been completed.)
- Reduction of emittance growth at higher source current. (This work is in progress.)
- Upgrade of the injector high voltage and control systems to accommodate the new source and column. (This work is in progress.)
- Testing of the sources, redesigned column, and low-energy beam transport (LEBT) modifications on the ISTS. (This work is in progress.)
- Installation and commissioning of the production ion source, the redesigned column, and the modified LEBT on the LANSCE accelerator.

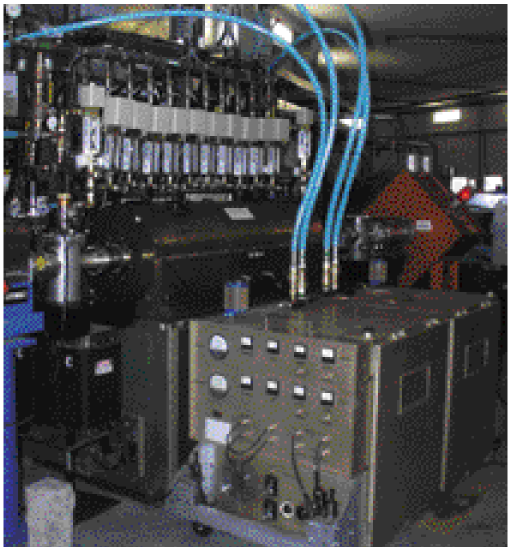


▲ **FIGURE 30**. *Photo of the new ion source designed and fabricated for LANSCE by LBNL.*

During 1999, we completed the fabrication of the two new production sources and the fabrication and testing of the new 80-kV column. We also completed the designs for the upgraded high-voltage power supply and control systems. The new source met current goals, operating at 40 mA on the ISTS. Work continues on meeting emittance goals. The magnetic repellers in the source have been identified as the likely cause of the higher-than-expected emittance. Redesign of the repellers is under way.

Proton Storage Ring Upgrades. The first phase of the PSR upgrades—redesign and refurbishment of the existing rf buncher (Figure 31)—was successfully completed in 1998 and comprised the following major elements:

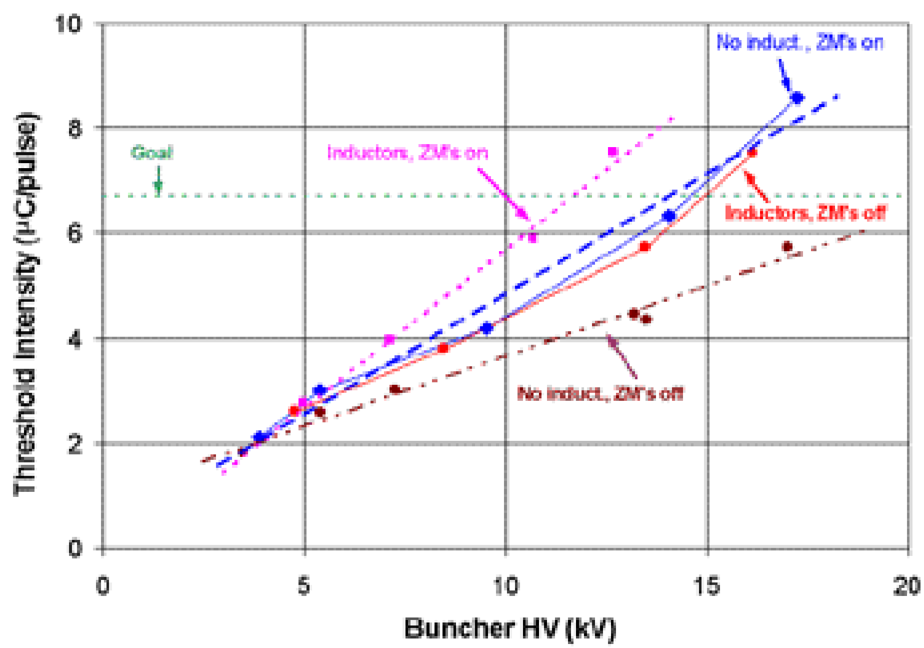
- The rf amplifiers were upgraded and a new intermediate power amplifier (IPA) was developed. The technical goal was to provide 18-kV peak rf voltage at 2.8 MHz.
- The buncher gap, ferrite assembly, and bias circuit were modified.
- Risk-reduction experiments, tests, and analyses were performed on the PSR.
- The electrical and cooling-water utilities were upgraded.



▲ **FIGURE 31**. *Refurbished rf Buncher in the PSR.*

The original design for the PSR upgrades called for a dual-harmonic buncher system: the existing buncher would operate at the fundamental ring frequency (2.8 MHz) and the second buncher would operate at the next harmonic (5.6 MHz). Tests using the newly upgraded buncher system were carried out in December 1998. Results indicated that the dual-harmonic buncher system was not effective in controlling the PSR instability. Based on tests conducted by the project in 1997 and 1998, alternate means of controlling the instability were identified.

During 1999, a series of successful PSR development tests were carried out to confirm that the PSR instability could be controlled at accumulated charge levels well above the 6.7-µC level required for the project. LANSCE was able to devote more time to these tests than initially planned because of the unfortunate difficulties experienced in restarting the Lujan Center. During the tests a new PSR record was set at 9 µC (see *http://lansce.lanl.gov/news/features/9908-psr.htm*), and consistent operation at levels above 8 µC were demonstrated. These results were achieved using a combination of inductive inserts, sextupoles, and skew quadrupoles (Figure 32). In addition, improved diagnostics were installed to better measure electrons in the beam and improve our understanding of the PSR instability. The PSR tests included collaborators from Argonne National Laboratory (ANL), ORNL, and Brookhaven National Laboratory (BNL). A technical workshop was held in September to analyze results and discuss upgrade options. Work is continuing on characterizing slow-beam losses and determining what will be the most effective combination of elements for meeting project technical goals.



▲ **FIGURE 32**. *Data indicating the effects of sextupoles (ZMs) and inductors on the PSR instability threshold.*

2.4.1.2 Spectrometer Development

The spectrometer development project will add five neutron-scattering instruments to the Lujan Center at LANSCE. The individual instruments are being designed and constructed by collaborative spectrometer development teams (SDTs) involving participants from federal laboratories, universities, and industry. One of the instruments is a structural biology spectrometer funded by the Office of Biological and Environmental Research (OBER). The Office of Basic Energy Sciences (OBES) is funding the remaining four instruments. A key project goal was to select a suite of OBES spectrometers that would maximize the overall scientific benefit to the national scientific community. To achieve this goal, competitive selection of the instruments was an integral part of the project. An external proposal evaluation committee (PEC), which is representative of the research and development community, has been set up to formally review proposed instruments.

During 1999, the following three instruments were in the construction stage:

- Protein Crystallography Spectrometer
- Spectrometer for Materials Research at Temperature and Stress (SMARTS)
- High-Pressured Preferred Orientation (HIPPO) Spectrometer

The following two instruments are in the planning stage for a 2000 start.

- The High-Intensity Chopper Spectrometer (HELIOS) is a high-intensity inelastic spectrometer planned for flight path 8.
- The High Resolution Energy Machine (HERMES I) is a crystal back-scattering instrument planned for flight path 11B.

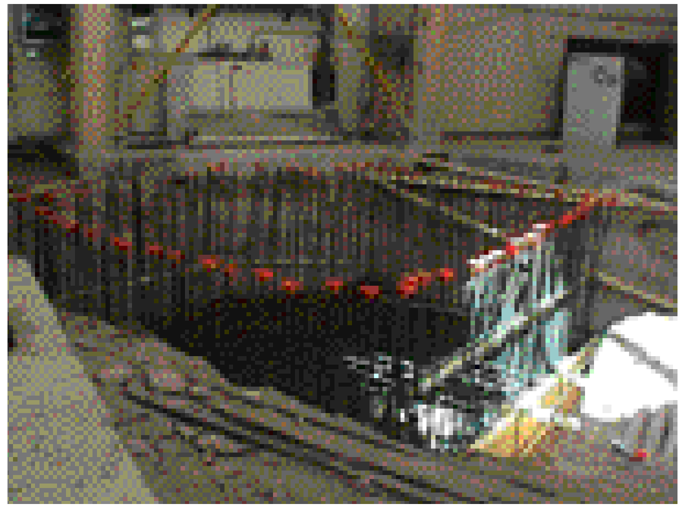
Protein Crystallography Spectrometer. The Protein Crystallography spectrometer is an OBER-funded neutron diffractometer designed for structural biology. The instrument will be located on flight path 15 viewing a partially coupled high-intensity water moderator with beryllium reflector. The instrument will include a large position-sensitive two-dimensional detector that allows horizontal and vertical scans. The detector is being designed and fabricated by Brookhaven National Laboratory.

During 1999, the beam-line design for the protein crystallography spectrometer was completed, reviewed, and approved for construction by LANSCE management. The mercury shutter and the shutter shielding were installed on flight path 15. The crystal goniometer (Figure 33) and motor/encoder control system were completed and successfully integrated. BNL completed and delivered a test detector, which was used to test the detector electronics with the LANSCE-developed data-acquisition electronics.

▲ **FIGURE 33**. *Protein Crystallography Crystal Goniometer.*

Spectrometer for Materials Research at Temperature and Stress. SMARTS is an OBES-funded powder diffractometer optimized to measure strain on both very large and small samples within a variety of sample environments. The instrument will have two principle modes of operation: strain scanning and material testing. In the strain-scanning mode, SMARTS will be capable of measuring stress distributions in engineering components and other samples. In the materials-testing mode, SMARTS will be capable of carrying out measurements of materials under load, at high temperatures, and in controlled atmospheres. SMARTS will be located on flight path 2 viewing a high-resolution water moderator. The instrument will include a neutron guide to enhance the flux on the sample, the capability of accommodating a sample with a total mass of at least 500 kg, and the capability of carrying out *in situ* strain measurements on samples at 180 kN and at 1500°C.

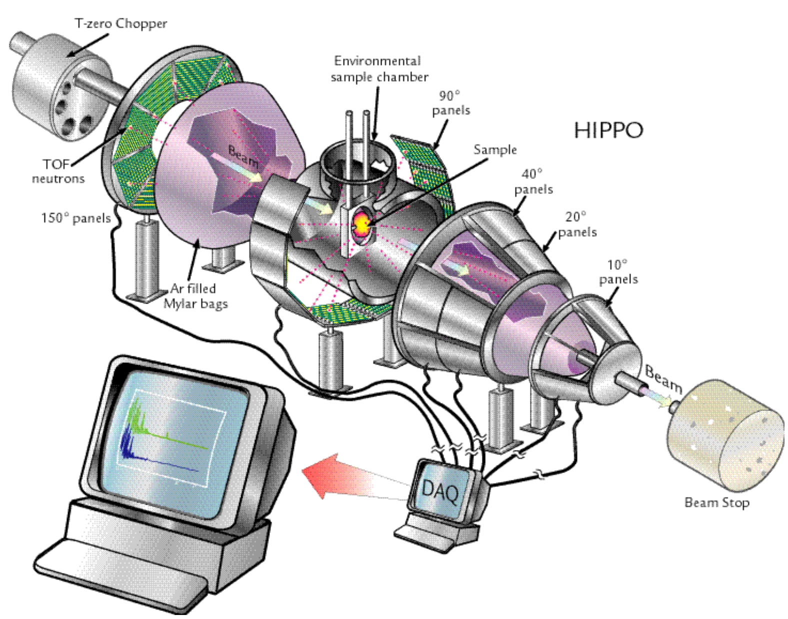
During 1999, the SMARTS beam-line design was completed, reviewed, and approved for construction by LANSCE management. The mercury shutter and the shutter shielding were installed on flight path 2. The ER1 and ER2 floor modifications were completed. These modifications included a large pit in ER2 to accommodate the translator and footings to provide isolated support for the neutron guide (Figure 34). Design of the neutron guide was completed, and its components were fabricated. The translator was completed. Detailed designs for the cave and mezzanine were completed and sent out for bid. The data-acquisition electronics and computer hardware were designed and fabricated. Visit *http://lansce.lanl.gov/news/features/smarts/htm* for more information on SMARTS.



▲ **FIGURE 34**. *SMARTS translator pit excavation in ER2 show the concrete forms and rebar.*

High-Pressure Preferred Orientation Spectrometer. The HIPPO instrument is an OBES-funded high-intensity powder diffractometer designed for texture measurements (Figure 35). HIPPO will have the capability to study samples at high pressure and high and low temperatures. The instrument will be located on flight path 4 viewing a high intensity water moderator. The instrument will include detector banks at (nominally) 150°, 90°, 40°, 20°, and 10° (1,384 detectors, 4.6 m^2) and a sample changer capable of rapid interchange of samples.

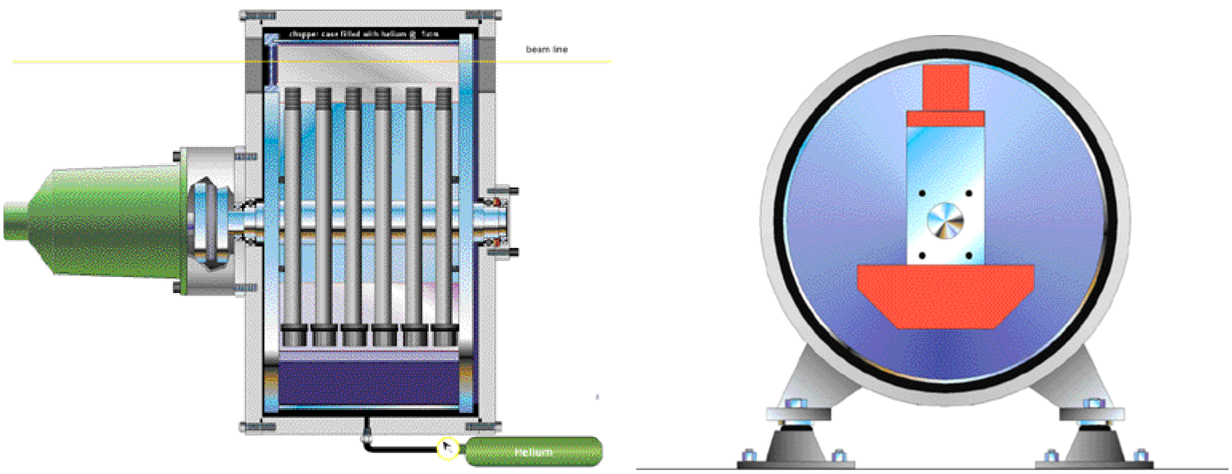
During 1999, the HIPPO beam-line design was completed, reviewed, and approved for construction by LANSCE management. The mercury shutter and the shutter shielding were installed on flight path 4. The bulk of the beam-line components and shielding have been fabricated and are ready for installation. The electronic and mechanical designs of the detector panel were completed, prototyped, tested, and integrated with the data-acquisition electronics. Procurement and fabrication of the electronics and computer hardware were completed and all 1,384 detectors were procured. The sample changer was designed, fabricated, and tested.



▲ **FIGURE 35**. *Exploded view of HIPPO spectrometer showing the sample chamber surrounded by five conical rings of detector tubes. Incident beam travels from left to right of figure. Argon-filled Mylar bags are used to reduce incoherent scattering in secondary flight paths.*

Common Technical Elements. To meet requirements for the new instrument suite, LANSCE is building new data-acquisition systems based on commercial software, developments from the controls community, and Web tools. In 1999, hardware prototypes and a first version of the data-acquisition software were completed. The detectors, preamplifiers, and time-of-flight modules passed in-beam tests following extensive bench testing. Currently this hardware is being replicated in production quantities for HIPPO, SMARTS, and Protein Crystallography. The first software release was completed in May. A second release that will add functions to facilitate instrument commissioning is in development.

During 1999, design of the new Lujan standard mercury shutter system was completed, and shutters were fabricated and installed for the Protein, HIPPO, and SMARTS instruments. The new shutter design will provide increased safety and reliability of operations and improved performance; opening and closing the new shutters is ten times faster than previous shutter systems. A standardized T_0 chopper design was developed and will be used by all three instruments (Figure 36).



▲ **FIGURE 36**. *These diagrams show side and front views of the SPSS T_0 chopper design. This design will be used for the HIPPO, SMARTS, and Protein Crystallography instruments and is expected to become the standard design for future spectrometers at the Lujan Center. The rotor is a three piece design with an Inconel shield, carbon steel counter balance, and aluminum block. The design employs a wind shroud which will allow operation up to 3600 rpm.*

2.4.2 Isotope Production Facility Project

The Isotope Production Facility (IPF) project provides for the construction of a new target-irradiation facility, which will use a 100–MeV proton beam to produce medical and other radioisotopes. Beam will be extracted from the existing LANSCE accelerator by installing a pulsed (kicker) magnet and extending a new beam line to the target-irradiation facility. The project scope includes design and construction of a beam-line tunnel and targeting area, design and construction of an above-ground building to house mechanical and remote-handling equipment, design and construction of an accelerator beam line, design and implementation of modifications to one segment of the LANSCE accelerator, and design and construction of target-irradiation and remote-handling systems. Detailed descriptions and technical specifications for each of these systems are set forth in the IPF conceptual design report (CDR-DP-97-026, August 7, 1997), which is available online at *http://pearl1.lanl.gov/ipf/*.

The total estimated cost for the project is $14 million. Other project costs are estimated at $1.54 million, resulting in a total project cost of $15.5 million. The baseline schedule calls for completion of design in September 1999, completion of construction in December 2000, and project completion in May 2001.

A contract for design of the facility structures was awarded to Merrick and Company, Inc., in early 1999, and the facility design was completed and approved in September 1999. Merrick was also awarded a contract for design of a hot cell to be installed inside the new facility. This design was 50% complete at the end of the 1999 fiscal year. Design of the beam-line components was conducted internally by a combination of Laboratory groups: ESA-DE, LANSCE-1, LANSCE-2, and LANSCE-6. Collectively, the beam-line design effort made excellent progress and was approximately 70% complete at the end of September. ESA-DE was awarded the target-design work package and completed the preliminary target design in FY99.

The kicker magnet fabrication contract was awarded to Fermi National Accelerator Laboratory (FNAL) in July. The kicker magnet is a technically complex, long-lead item critically important to the overall success of the project. Work at FNAL progressed on schedule throughout the remainder of the fiscal year.

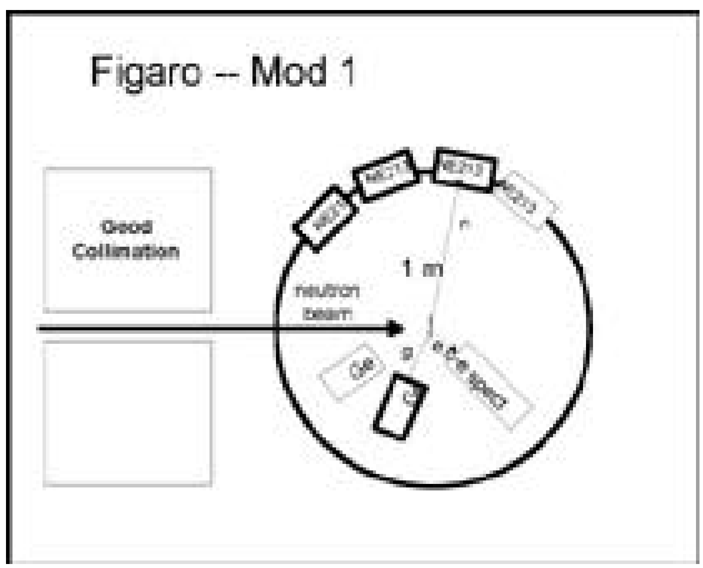
The IPF project was subjected to an external independent assessment in June. The assessment team submitted its report to DOE and Congress in August. The external independent assessment, which was generally supportive of the IPF project, concluded that the IPF project satisfies the DOE mission need and justification requirements. The assessment report contained four findings and noted two noteworthy good practices.

2.4.3 FIGARO: A New Facility for Studying Neutron Reactions That Produce Gamma Rays

The Fast Neutron-Induced Gamma-Ray Observer (FIGARO) was established this year (Figure 37) as a complement to the GEANIE facility at WNR. This new capability is intended to extend our research into nuclear reactions and nuclear structure using gamma rays as the principal probe. FIGARO will also be able to detect emitted neutrons and perhaps internal conversion electrons.

The scientific goals of FIGARO include the following:

- investigation of nuclear level densities using gamma-ray transitions as an indicator of angular momentum populated in the reaction;
- investigations of pre-equilibrium reactions;
- investigation of cross sections and neutron-emission spectra in (n,n') excitations;
- assessment of whether a conversion electron spectrometer is useful at WNR; and
- assignment of proposed research at FIGARO. (GEANIE is significantly oversubscribed at present, and some of the proposed research could be carried out at FIGARO.) Visit *http://lansce.lanl.gov/research/pdf/wender1_00.pdf* for more information on this subject and other activities being conducted at WNR.



▲ **FIGURE 37**. *FIGARO Mod 1, showing two germanium detectors for high-resolution gamma-ray detection, four NE213 scintillators for detecting neutrons, and a possible conversion-electron spectrometer for detecting internal conversion electrons. The gamma-ray detectors and the conversion electron spectrometer tag the reaction in two ways: (1) by identifying the residual nucleus and (2) by identifying the angular momentum of states populated following the gamma-ray cascade to low-lying levels. The neutron detectors in coincidence with the other detectors give the emitted neutron energy by time-of-flight over the flight path of 1 m or*

2.4.4 Ultra-cold Neutron Source

An international collaboration working at LANSCE has developed what promises to be the most intense ultra-cold neutron (UCN) source in the world—a source that ultimately will be competitive with other approaches in searching for new physics. This source works by moderating neutrons from a spallation target into the UCN regime using solid deuterium at 5 K. Our initial physics research will center on a measurement of the asymmetry in the direction that electrons are emitted with respect to the neutron spin in the beta decay of polarized UCNs. Because of the unique properties of UCNs, we expect to greatly reduce all of the major systematic problems that have plagued reactor measurements of the beta asymmetry. We expect to determine the weak vector coupling constant (a fundamental constant of nature) with unprecedented accuracy. Comparing our measurement with that predicted by the standard electroweak model, which unifies the electromagnetic and weak interactions within the nucleus of an atom, we can carry out a sensitive search for possible new physics predicted by unified field theories, such as the existence of new particles that mediate the weak interaction. In addition, if a sufficiently intense UCN source can be produced at LANSCE, new applications using neutron scattering, including surface studies and measurements of protein structure, may open.

We have already produced a significant flux of UCNs and measured both the production rate and the lifetime of UCNs in the SD_2. Our first observations indicated a much shorter lifetime (and therefore more absorption) in the source than we had calculated. Although we tried different means of freezing the deuterium and varied the SD_2 temperature and volume, we observed little change in the UCN rate. In the summer of 1999, we realized that the factor limiting the production rate was the fraction of "para" deuterium in which the spins of the two deuterium nuclei are lined up to form a total nuclear spin of 1. Deuterium also exists in the "ortho" state in which the spins of the two deuterium nuclei add up to form a total nuclear spin of 0. By converting the fraction of molecules from the para state into the ortho state (which is the ground state) using a cryogenic converter, we observed an increase in UCN rates. Based on our understanding of the physics involved in UCN production in SD_2, we now believe we can construct a dedicated UCN source at LANSCE that will be the most intense in the world.

2.4.5 The 30-T Pulsed Magnet

We continue to make progress toward providing an intense pulsed magnetic field capability at LANSCE in cooperation with the National High Magnetic Field Laboratory. While the eventual goal is to achieve 30 T and a lifetime of 10^7 cycles, we expect the first magnet to run at fields up to 23 T at this lifetime. The first magnet will be delivered in 2000. Power supply components are currently being ordered, and we have identified suitable surplus capacitor banks at the Princeton Plasma Fusion Laboratory. The project was subjected to external review in January 1999 and had its first safety review in September 1999. In January 1999, we held a workshop entitled "Scientific Opportunities for Neutron Scattering at 30 T," and we identified a variety of exciting potential experiments.

2.4.6 Detector for Advanced Neutron-Capture Experiments

We made significant progress in developing the detector for advanced neutron-capture experiments (DANCE), although the relatively short period of beam availability limited the amount of data that were obtained. Moving the experiment from flight path 14 to flight path 2 required the construction of a new beam line and collimation and shielding, although many components from previous experiments were reused. Most of the beam time was devoted to understanding and minimizing the experimental backgrounds.

A considerable design effort was directed toward the full DANCE instrument on flight path 14. The design will consist of a 160-element BaF_2 crystal "soccer ball" array of four different crystal shapes. The array parameters were designed using results from a Monte Carlo simulation of the detector by the Karlsruhe collaborators (see Los Alamos National Laboratory report LA-UR-99-4046 for results of the simulation).

The mechanical design of the detector support was carried out by Chamberlin Enterprises of Los Alamos. The array is designed to split in half through the center to allow for inserting targets sealed in a removable target tube. The use of a removable sealed target tube will permit safe handling of the radioactive targets that will be measured in the DANCE experimental program. The radioactive material will be inserted into the tube and sealed at CST facilities before the entire tube is brought to the Lujan Center.

Finally, a great deal of attention has been directed to designing the beam line and shielding for DANCE on flight path 14. The shutter and ER-1 shielding package was designed by LANSCE-12 to meet the radiation exposure criteria as part of a "unified" shielding system with flight path 15. The flight path 14 shutter has been installed and tested. The design of the ER-2 portion of the flight path is under way with the assistance of LANSCE-12.

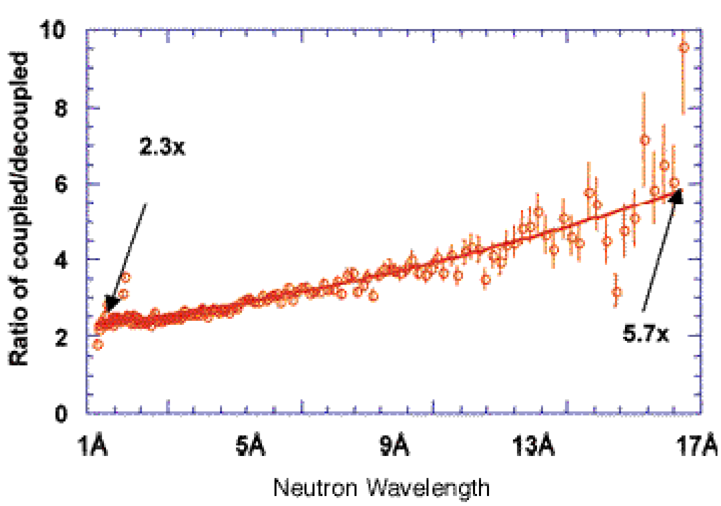
2.4.7 New Partially Coupled Moderators at the Lujan Center

The Lujan Center is the first spallation neutron source to exploit the increased neutron flux provided by coupled moderators. A new coupled liquid-hydrogen moderator (Figure 38), installed as part of the LANSCE Reliability Improvement Project, provides an increase of approximately 2.5 times over the previous decoupled moderator (Figure 39). Both the small-angle diffractometer (the low-Q Diffractometer, LQD) and the Surface Profile Analysis Reflectometer (SPEAR) benefit from this increased flux.

▲ **FIGURE 38**. *Decoupled liquid hydrogen source installed at the Lujan Center.*

The increase in flux is a result of the interaction of the moderator, the reflector surrounding the moderator, and the lack of decouplers. Because the time distribution of the pulse produced by the moderator are essential to data analysis and instrument design and optimization, LANSCE-12 personnel measured time distributions at several wavelengths using a small crystal analyzer spectrometer and compared these results with Monte Carlo calculations of the time distributions. A new method was developed to analyze the time distributions within the Ikeda-Carpenter formalism. The method enabled us to obtain reliable information on the decay constants of the pulse at all wavelengths. The measurements covered a range of wavelengths from 1 to 20 Å, showed shorter tails than the calculation, and required only one time constant for the fall. The discrepancy between the measurements and calculations was resolved when a narrower energy range was selected in the calculations bringing the calculations more in line with the energy range in a diffraction peak.

The integrated neutron intensity for the coupled liquid hydrogen moderator was measured using the area detector on the small-angle-scattering diffractometer (LQD) and compared to a previous measurement on the decoupled moderator. The integrated intensity is a factor 2.5 larger, also in good agreement with predictions.



▲ **FIGURE 39**. *Intensity gain provided by the new decoupled liquid hydrogen moderator at the Lujan Center depends on neutron wavelength. The average gain factor is 2.5.*

2.5 Future User-Facility Upgrade Projects

2.5.1 N+p→D+γ

The n+p→D+γ experiment seeks to measure a small asymmetry in the direction of emission of the γ ray with respect to the neutron polarization direction when polarized neutrons are captured by hydrogen. The asymmetry is non-zero because the weak interaction between nucleons has a small parity-violating part. The asymmetry can be related to the size of the component of the parity-violating force that is mediated by π exchange, H_π. There is no ambiguity in the interpretation of the asymmetry due to nuclear structure because the two-body problem can be solved exactly.

The experiment is being developed by a collaboration of scientists from LANL, Michigan, Indiana, Berkeley, NIST, New Hampshire, KEK, and Dubna. LANSCE and DOE have successfully reviewed the scientific merit and technical feasibility of the experiment. The experiment has had a successful technical review for cost and schedule. On the basis of these reviews, LANSCE has approved the experiment and assigned a cold flight path (flight path 12) to the experiment. The DOE has provided capital funding for the construction of the beam line and experiment. Construction of flight path 12 is being done in coordination with construction of flight path 13, which began in 1999.

The apparatus consists of a super-mirror neutron guide that transports the cold neutrons from the liquid-hydrogen moderator to the detector located 19 m from the moderator. A frame overlap chopper eliminates neutrons with energies less than 1 meV. A polarized ^{3}He neutron spin filter polarizes the neutron beam, and the neutron spin is reversed from beam pulse to beam pulse by a radio-frequency spin flipper. The polarized neutrons stop and capture in a liquid para-hydrogen target. The target is surrounded by an array of 48 CsI gamma detectors. The instantaneous rate in the gamma detectors is about 10^{+9} Hz, which is too large for pulse counting. The light from the CsI is converted to a current by vacuum photodiodes, and low-noise pre-amplifiers amplify the current. The pre-amplifier signals are processed by linear analog electronics and recorded by transient digitizers. The signal-processing chain detects the asymmetry without degradation of the counting statistics limit. The neutron flux is monitored before the ^{3}He neutron spin filter and after the liquid para-hydrogen target. All components of the experiment have been either built and tested or prototyped.

We expect to complete construction of the beam line and detector in 2002. In one month of data acquisition, we will match the statistical precision of all previous experiments to measure H_π. The data collection in these previous experiments took five years. We plan to collect data for eight months and measure H_π with a statistical error of 10% of its expected value. Considerable effort has been devoted to analyzing potential sources of systematic error and eliminating these sources by the design of the experiment. The systematic error will be negligible, less than 10% of the statistical error.

2.5.2 Neutron Electric Dipole Moment

Though the neutron has no net charge, the fact that it is a composite particle implies that it could have a non-uniform distribution of charge within its volume. Such a charge distribution has been observed, but it would be particularly interesting if this distribution led to an electric dipole moment (EDM), which is best visualized as a slight displacement of the positive and negative charges along the spin direction. Such a neutron EDM is important and would be a manifest indication of time-reversal non-invariance. A non-zero neutron EDM would also have profound implications for important questions in cosmology. The search for a neutron EDM has been under way for several decades and has reached the point where reactor-based experiments are now limited by intensity issues. Several years ago it was suggested that the limits on a possible neutron EDM could be significantly lowered by using a novel technique in which neutrons are scattered almost to rest in a volume of extremely cold (~1 K), extremely pure superfluid helium. A collaboration between P Division, Harvard University, and LANSCE is currently carrying out a series of tests at the Lujan Center to verify the feasibility of this concept. If successful, this program would develop into a major effort with important consequences for nuclear and particle physics.

2.5.3 Development of ASTERIX and IN500

The goal of the ASTERIX project is to develop a polarized neutron beam at the Lujan Center. The experiments envisaged include studies of thin-film and artificially structured materials using polarized neutron reflectometry, characterization of polarized-neutron diffuse scattering from magnetic order in bulk materials, and studies of materials subjected to large magnetic fields. To achieve this goal, we will develop a polarization cavity with a polarizing efficiency of greater than 96% for all neutrons with wavelengths longer than 3 Å, a statistical spin-flipper with flipping times less than 1 µs, and polarization analysis covering large solid angles. In May and June of 1999, Mike Fitzsimmons of LANSCE fabricated 96 doubly coated, 3Θc polarizing transmission supermirrors at the Paul Scherrer Institute in Switzerland. Their high remanence allows these mirrors to polarize the neutron beam for either spin state in near zero field conditions

The goal of IN500 is to develop and test a prototype spectrometer for inelastic cold-neutron-scattering spectroscopy that will allow spallation sources to compete with the leading reactor facilities in this crucial area of neutron research. In 1999, the physical design of the beam-delivery system was completed, based on the novel concepts of reduced-loss ballistic neutron guide and disc chopper system capable of providing repetition rate multiplication. Engineering design is in progress for the installation of a beam shutter on flight path 13 together with the in-pile neutron-optical-beam extraction system and an integrated shielding around the beam shutters of flight paths 12 and 13. We are conducting Monte Carlo simulations in support of the pre-engineering design, which includes the sample area and detector system, spectrometer shielding systems, and further performance evaluations.

2.5.4 Proton Radiography Kicker Project

The 800-MeV beam switchyard is used to direct beams from the linear accelerator to various experimental areas and for injection into the PSR. Simultaneous beam delivery to Lines B and C and Line D (PSR injection) is not possible at present. Generally, a few hours are required to accomplish the required changes to allow the H^- beam to be directed from Line D to Lines B and C. Delivery of this beam to all users is interrupted during this transition period. The initial project goal was to find a cost-effective, technical solution that would allow simultaneous, uninterrupted beam delivery to Line D and delivery of a "tailored" H^- beam pulse to either Line B or Line C on the demand of the experimenters while preserving all existing operational and tune-up modes.

A technical solution was selected in August 1999. This solution requires a configuration of two pulsed-kicker magnets and two direct-current magnets to divert beam from Line D. Beam pulses delivered on demand will be diverted from the 100-Hz beam normally delivered to WNR. The solution we have selected incorporates an achromatic bend with magnetic-field values well below the magnetic-stripping limit for the 800-MeV H^- beam. Implementation of the kicker system will include construction of the two pulsed-kicker magnets, similar in design to the PSR injection kicker magnet (RIKI), their associated modulators, and the two direct-current magnets. Procurement of two direct-current magnet power supplies will also be required. Installation of the kicker system will require modifications to the existing beam line, including removal of the LD-KI–01/02 fast kickers. Removal of the LD-KI modulators has already been completed.

Significant progress was made in characterizing the existing RIKI kicker magnet and in producing detailed engineering drawings that can be used for procurement after engineering review and sign-off. A kicker-magnet modulator design was reviewed and trade-off studies were performed to support a decision to build in-house modulators.

A revised project cost estimate was produced assuming a two-year project duration in FY00/FY01. The unburdened costs for FY00 and FY01 were estimated to be $1,224,000 and $399,000, respectively, without any project contingency. A project contingency of an additional 30% is estimated at this time. A baseline project schedule was also completed incorporating information from the revised cost estimate.

2.6 Planning

2.6.1 Budget Planning

As noted by the Root Causes and Systemic Issues Team (see Section 1.4, Safety Stand Down), one of the underlying reasons for poor safety performance at LANSCE is lack of resources. This same insufficiency also affects the reliability of beam delivery. To address the resource issue, LANSCE management has undertaken a detailed evaluation of the minimum resources required to operate the User Facility reliably and safely for eight months per year. This plan was carefully benchmarked against the resources used at other United States and European facilities involved in similar activities. The budgets required are given in Table 6. The split in budget requests between the Offices of DP and BES is determined on the basis of an agreement between DP and BES according to which DP is responsible for the operation of the linear accelerator and BES contributes toward the operating costs of the PSR and the Lujan Center target and spectrometers. As new spectrometers are brought on line at the Lujan Center, about 4.25 additional FTEs will be required to operate a user program for each spectrometer.

TABLE 6. Funding Required for FY00 in FY99 ($K).*

	Required Funding		Available in FY99	
	DP	**BES**	**DP**	**BES**
Accelerator and experimental area operations	21,950	3.750	17,700	3,000
Accelerator electricity	3,500	500	4,400	500
WNR electricity	1,900			
Lujan Center user support	1,600	4,200	1,400	500
WNR user support	1,900		1,600	
User administration		900		600
Direct-funded facility management	3,600		3,600	
R&D at LANL	12,000	2,500	7,000	1,700
Operations and R&D total	46,450	11,850	35,700	9,000
Annual infrastructure investments	3,000		7,700	
Grand total	49,450	11,850	43,400	9,009

*FY99 available funding includes carryover ($2.7M DP + $0.8M BES).
FY99 BES capital equipment of $600K (including carryover) not included.
Funding for SPSS Enhancement Project not included.
APT support for electricity ($1.5M) and FM ($1.6M) not reflected in FY99 budget.

2.6.2 Infrastructure Planning

As part of the safety stand down, a team was commissioned to determine the quantity and state of the legacy equipment for which the Division has inherited responsibility. Much of this equipment (which includes cables, magnets, power supplies, spectrometers, shielding, etc.) was abandoned in place by the nuclear-physics research program that was the major sponsor of the linear accelerator until 1993. Working only with the legacy equipment identified in the database of concerns generated during the safety stand down, the team made a very rough estimate that $2 million would be required to correct the legacy issues. This cost does not include dismantlement of Area A and its preparation for another mission (such as a target station for a long-pulsed spallation source), which was estimated to cost $8 million. A prioritized plan for the safe disposal of legacy equipment will be developed during the coming year.

In calendar year 2000, the Division plans a full evaluation of the major infrastructure improvements that will be required to ensure the long-term success of the present facility and the availability of the linear accelerator as an injector into the planned AHF.

2.6.3 Manpower Planning

As part of strategic planning, LANSCE undertook a strategic staffing plan that concentrated on FY00 with a look toward the future. Input from program offices and funding expectations were used for a first determination of a skills database—a database that was then iterated with group offices and program offices several times. Skills or capabilities were broken into thirteen categories for technical staff members and fourteen categories for technicians. This information was used to effect transfers within the Division and to identify key resources external to the Division needed. Based on the best information available, the Division will need to hire 40 FTEs (including contractors, post-docs, and students) to meet commitments and deliverables by the end of FY00.

Because there are several accelerator activities at Los Alamos, this strategic staffing plan was taken a further step. The Division Directors of LANSCE and DX and the Program Director of APT formed an Accelerator Resource Planning Team with a charter to look at key resources, overlaps, needs, and interfaces. Data collection is under way for planning accelerator-related resources over the next five years with a focus on immediate issues. Programs, divisions, and activities involved in this exercise include LANSCE, DX, APT, ATW, SNS, AHF, IPF, P, and DAHRT.

2.6.4 Science Planning

The Division has begun to develop a strategic science plan for the LANSCE User Facility. This plan is based on a determination that the overarching goal of LANSCE Division is to operate a successful National User Facility for defense and civilian research that provides a long-term strategic advantage to LANL. A prerequisite for achieving this goal is that the accelerator and associated experimental areas operate safely, reliably, and predictably. We are carefully addressing this issue by evaluating resource needs, seeking appropriate budgets, and allocating resources to tasks in relation to their importance to safe, reliable operation.

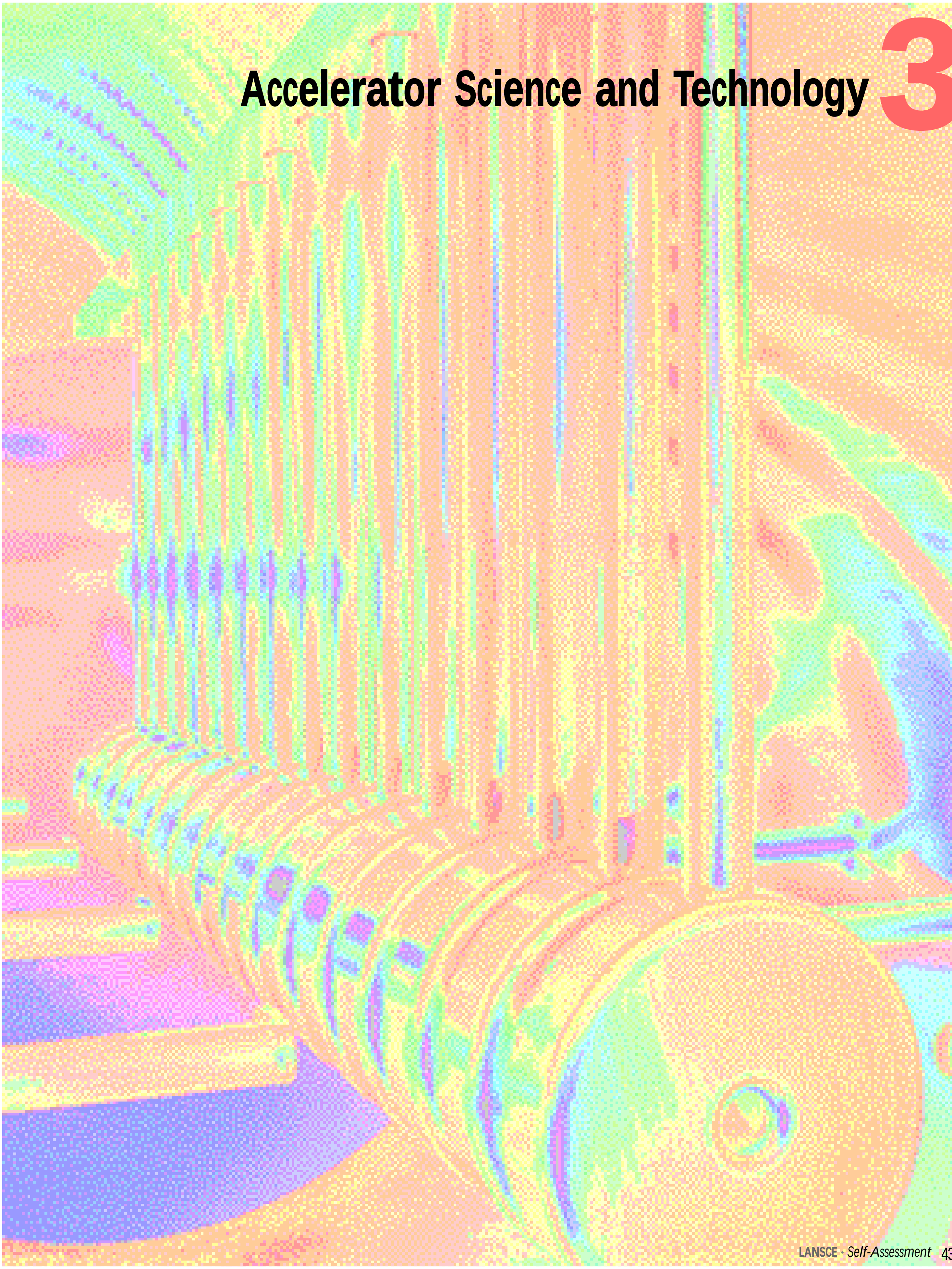
To achieve its goal, LANSCE will pursue the following science strategies:

- execute an in-house R&D program in which defense and civilian R&D are tightly coupled and in which the two communities can learn from and support one another;
- focus in-house R&D on activities where collaborations with programs in other LANL divisions provide opportunities for synergy; and
- develop close collaborations with scientists in western region universities, particularly the University of California and New Mexico universities.

The execution of this plan relies on funding from the DOE Offices of Defense Programs and Basic Energy Sciences, complemented by institutional investments that leverage these funding sources and promote their synergies. Table 7 provides brief synopses related to the implementation of these strategies.

TABLE 7. Synopses of Science Strategies.	
Strategy	**Synopsis**
Execute an in-house R&D program in which defense and civilian R&D are tightly coupled and in which the two communities can learn from and support one another.	Several spectrometers at the Lujan Center and WNR provide important resources for both defense and civilian research and provide a natural venue for close scientific interactions between defense and civilian researchers. Examples include SMARTS and HIPPO, which are being constructed at the Lujan Center as part of the SPSS Enhancement Project jointly funded by DOE's Offices of DP and SC/BES; the DANCE spectrometer, under development at the Lujan Center by CST scientists using LDRD funds; and the GEANIE detector at WNR. The Laboratory's BES programs in materials science have been reorganized to focus on three areas: polycrystalline deformation, complexity in hard matter, and complexity in soft matter. Several of the research topics in these areas overlap strongly with defense R&D at the Lujan Center. We will strengthen this synergy as new spectrometers come on line at the Lujan Center. Under MST Division leadership, LANL is planning a DOE-funded nanoscience research center—a centerpiece of which is the neutron-scattering capability at the Lujan Center. We will use the Lujan Center to expand basic materials R&D at LANSCE.
Focus in-house R&D on activities where collaborations with programs in other LANL divisions provide opportunities for synergy.	To ensure scientific and programmatic excellence of the R&D program at LANSCE and appropriate involvement of other LANL technical divisions in planning and executing R&D at LANSCE, we have established a Science Council comprising senior Laboratory scientists from the defense and civilian research arenas. All of the contributions that LANSCE will make to four stockpile stewardship campaigns involve collaborations with other technical divisions. Other examples of growing interaction within LANL include a collaboration with the National High Magnetic Field Laboratory to develop a unique 30-T pulsed magnet for use at the Lujan Center, collaborative projects with MST Division in the areas of strain measurement and correlated electron physics, collaboration with B Division scientists on construction of a protein crystallography spectrometer at the Lujan Center, and collaboration with P Division on programs in cold-neutron nuclear physics and fundamental physics measurements using UCNs. To promote enhanced collaboration between LANSCE and other technical divisions, we have proposed the creation of an LDRD category team for neutron-scattering research that will provide support to scientists in divisions other than LANSCE to enable them to use neutron scattering in support of their experimental or theoretical research. The new category team will coordinate the management of successful LDRD projects undertaken recently by P, MST, CST, and T Division scientists who have contributed to work at the Lujan Center.
Develop close collaborations with scientists in western region universities, particularly the University of California and New Mexico universities.	LANSCE has established joint professorships with New Mexico State University (NMSU) and University of California at San Diego (UCSD). The NMSU position was filled two years ago following a national search. The UCSD position, for which start-up funds will be provided from UCDRD funds, has recently been offered to an internationally reputed scientist. The University of California at Santa Barbara has expressed strong interest in a similar position. Further positions are being discussed within the Institute for Complex Adaptive Matter initiative. Many of the new instruments under construction at the Lujan Center involve strong collaboration with UC campuses (in one case with eight of the nine campuses). To make it easier for UC faculty to make neutron scattering a part of their educational and research activities, we have obtained UCDRD funds to support the participation of UC students in experiments at LANSCE. At the end of October 1999, we began a series of outreach activities to increase the involvement of UC faculty and students in LANSCE experiments.
Further refinement of this plan and the full involvement of other LANL divisions in its execution will continue during the calendar year 2000.	

Accelerator Science and Technology 3



3 ACCELERATOR SCIENCE AND TECHNOLOGY

Research and development in the underlying science and technology for accelerators provides an underpinning for numerous programs of national interest. This work is symbiotic with operation of the LANSCE User Facility and provides an expertise base that can assist the Laboratory moving forward in areas of interest for future programs.

3.1 Noteworthy Scientific, Technical, and Programmatic Achievements

3.1.1 Future Plans for Large-Scale Accelerator Simulation

The design of next-generation particle accelerators will require a new level of modeling as we push the frontiers of beam intensity, beam energy, and accelerator system complexity. Involvement in high-performance computing efforts, such as the DOE Grand Challenge in Computational Accelerator Physics, will have a major impact on the design, on performance optimization, and ultimately on the success of next-generation accelerators. High-resolution modeling and confidence in accelerator designs can lead to cost optimizations that may save hundreds of millions of dollars in construction and operating costs. But beyond impacting major DOE projects, the application of terascale resources, such as the LANL/ACL 2048 processor Nirvana system, can also open the door to using large-scale simulation as a tool of discovery as we advance toward new regimes of beams under extreme conditions.

LANL is playing a leading role nationally in facilitating the use of terascale resources within the accelerator community. In particular, LANL in 1999 spearheaded an effort that resulted in a code-development collaboration involving LANL, Stanford Linear Accelerator Center (SLAC), LBNL, FNAL, and BNL. This represents a major change from "business as usual," where for years, development of accelerator simulation codes took place alongside projects in isolated groups working at institutions spread throughout the country. By working together, these and other laboratories will develop an extendable, maintainable, reliable terascale capability and bring it to bear on the design of next-generation accelerators. Such an approach will help ensure the success of next-generation accelerators, while reducing design time, developing optimal designs, and minimizing cost and risk. By making use of the latest high-performance computing resources and developing software and algorithms targeted to those resources, we will revolutionize the design, installation, construction, commissioning, and operation of the next generation of accelerators.

Several areas in which this effort can have enormous impacts are understanding beam-halo formation and its control, investigating details of SNS beam dynamics and the low-beam-loss design, investigating instabilities in rings and stability regions for future colliders, and understanding magnet system/beam transport interactions over large apertures in detail. A start in this important area was accomplished by studies supported by the Grand Challenge for accelerator simulation described below.

3.1.1.1 Progress in the Grand Challenge

The goal of the DOE Grand Challenge in computational accelerator physics is to develop a new generation of accelerator simulation tools targeted to high-performance computing platforms and to apply them to problems of national importance. In so doing, we aim to have a major impact on the design, performance optimization, cost, and ultimately on the success of next-generation accelerators. A major deliverable of the Grand Challenge is the IMPACT accelerator simulation code, which was developed by a multidivisional team at LANL and led by LANSCE-1. This code combines modern methods of particle-in-cell simulation with nonlinear magnetic optics, all in a high-performance computing environment. IMPACT is now being used in support of the SNS and APT projects. Thanks to the Grand Challenge, we are approaching real-world charge resolution in our beam dynamics simulations for the first time.

A primary purpose of the IMPACT code is to perform large-scale simulations of linear accelerator designs for projects such as SNS and APT. The goal of such simulations is to predict the location and amount of charge that will strike the beam pipe, resulting in particle loss and radioactivation. Such information is crucial, since future high-intensity linear accelerators will have to operate with extremely low losses to ensure that hands-on maintenance can be performed. IMPACT is also useful for fundamental studies of beam-halo phenomena. Working with Ingo Hofmann of Gesellschaft für Schwerionenforschung (GSI), we recently performed the first systematic studies of halo formation resulting from longitudinal/transverse coupling in intense charged-particle beams (see Section 3.1.2, *Beam-Halo Studies*).

In further LANL development of large-scale simulations, we have improved a three-dimensional, parallel, particle-in-cell code using a parallel-message passing paradigm. This enables a significant reduction in computing time by a factor of three to four. Some new functions for the error studies in the machine design and program-restarting function have also been added to the code. This code has been benchmarked with the presently used design code LINAC. Agreement is as expected. Using this code, we have done beam-dynamics simulations for the APT superconducting linear accelerator with 100 million macroparticles and seven sets of design errors. We have also used the same code to study beam dynamics in the SNS linear accelerator from the beginning of the drift tube linac (DTL) to the end of the coupled cavity linac (CCL) with up to 500 million macroparticles and the field distribution in each cavity to predict the aperture size in the design. A systematic study of the effects of macroparticle number used in the simulation on the maximum amplitude of the particles suggests that 100 million particles should be used for the maximum amplitude to reach a level of saturation. This study supported the choice of a 2-cm beam pipe radius in the former normal-conducting SNS linear accelerator design.

We have also developed a second-order stochastic leapfrog algorithm for the multiplicative noise Brownian motion. This new algorithm can be used in Langevin simulations to study intrabeam scattering in accelerators. Working with Andreas Adelmann of PSI/ETH Zurich, we have implemented a tree-based space-charge solver using POOMA (parallel object-oriented methods and applications) framework in MAD9. This code provides a capability to simulate the high-intensity beam in cyclotrons. For more information about the Grand Challenge, go to *http://lansce.lanl.gov/research/accelerators/ryne.htm.*

3.1.2 Beam-Halo Studies

The nonlinear and time-dependent space-charge force associated with root-mean-square (rms) mismatched beams has been identified as a major source of beam-halo formation in beams that are strongly influenced by space-charge forces. Beam-mismatch excites collective oscillation modes of the rms envelopes that resonate parametrically with the transverse or longitudinal oscillations of some beam particles. This interaction drives the particles to larger amplitudes. We have obtained numerical solutions to simple particle-core models that provide predictions for the halo properties, including approximate scaling formulas for the maximum halo amplitude.

Working with Robert Gluckstern and colleagues at the University of Maryland, we have studied three-dimensional beam equilibria and the evolution of these equilibria under mismatched conditions. We find that the longitudinal halo forms first for comparable longitudinal and transverse mismatches. Because of the coupling between longitudinal and transverse motion, a longitudinal or transverse halo is observed for a mismatch less than 10% if the mismatch in the other plane is large. We have also studied the effect of redistribution on the halo development mechanism. We find that the redistribution process for beams with nonstationary distributions leads to oscillations of the beam radius about an average value, which is "equivalent" to introducing a small initial mismatch for a stationary distribution. Working with Ingo Hofmann of GSI, we have performed the first systematic studies of halo formation resulting from longitudinal/transverse coupling in intense charged-particle beams using a particle-core model and three-dimensional, parallel, particle-in-cell simulations. We find that a coherent resonance between the transverse and longitudinal mismatch eigenmodes has the effect that a transverse "breathing mode" mismatch can excite a longitudinal mismatch and halo when the resonance condition is satisfied. With John Barnard and Steven Lund of Lawrence Livermore National Laboratory (LLNL), we have studied longitudinal halo formation, including rf nonlinear effects. We find that a particle can be lost from the rf bucket when it reaches sufficiently large amplitude longitudinally in the halo. These particles will lose synchronism with the rf wave. Such particles will lose energy and so be poorly matched to the transverse focusing field and consequently lost transversely.

An exciting development allows us to investigate for the first time beam-halo dynamics in periodic-focusing channels using the particle-core model. The method employs novel canonical transformations and a strobing technique to view the halo motion as distinct from envelope flutter. By applying this method, we found that in periodic-focusing systems certain particles initially not in the halo region can be brought into resonance with the core oscillation to become halo particles; this phenomenon explains how particles move into halos.

3.1.3 Coherent Synchrotron Radiation

Using the SPA at LANSCE, we have made the first clear measurements of beam-emittance growth resulting from coherent synchrotron radiation (CSR). We anticipate that CSR will be a potential source of major emittance growth in future x-ray free-electron lasers (FELs) and other applications requiring high-brightness electron beams. CSR is radiation from the entire electron bunch as the bunch travels in a circular path (as in a bend or bunch compressor). Wavelengths of light that are long compared to the electron bunch radiate coherently and lead to a large force on the electron bunch and to a potentially large emittance growth. The effect is worse for small electron bunches, is independent of beam energy, and scales as the total bend angle times the third root of the bend radius.

Using an 800-A, 1-nC electron bunch at 8 MeV, an emittance growth from 12 mm mrad to 45 mm mrad was measured in a 37° magnetic chicane. "Normal" space-charge effects (nonradiative) could only account for a small portion of this growth (to about 15 mm mrad). Also, it was shown that this emittance growth was not due to transport errors in the chicane. The emittance growth is consistent with simulations (given the experimental uncertainties) but somewhat larger than expected. Thus, this experiment confirms the existence of the CSR issue and provides a valuable data point for comparison to simulations. The CSR finding may have a significant impact on the designs of the anticipated Linac Coherent Light Source (LCLS) and Next Linear Collider (NLC).

3.1.4 Plasma-Wakefield Accelerator

With LDRD funding from, we demonstrated the highest gradients to date in an electron-beam-driven plasma-wakefield accelerator using the SPA. This 8-MeV accelerator produces electron bunches from 1 to 3 nC, with bunch lengths less than 1 ps, using a magnetic chicane buncher. A train of these bunches, each separated by about 9 ns, passes through a high-density gas, produced by a Mach 5 gas jet. By changing the nozzle on the jet, the interaction length of the gas can range in length from 1 to 9 mm. The gas density, which is very high, is on the order of 10^{19} per cm^3. The electron beam density can be as high as 10^{16} per cm^3. The electron bunches successively ionize the gas to a plasma of equal density, and once the plasma is established, the later electron bunches excite large-amplitude electric-field oscillations in the plasma that are suitable for particle acceleration. Previous gradients produced in this manner in earlier experiments were on the order of a few tens of MV/m. Gradients on the order of 1 GV/m should be able to be produced in a plasma of 10^{16} per cm^3 density with a drive electron beam of length less than 1 ps. The advantage of electron-beam-driven plasma-wakefield accelerators over laser-driven plasma-wakefield accelerators is that the phase of the accelerating plasma waves is trivial to control over arbitrary distances for the electron-driven devices, and these devices scale to large, multi-TeV machines.

We demonstrated that the full gas ionization for xenon occurs after only two electron bunches and thus provided a clear measurement of the anomalous effect of secondary ionization. If only primary ionization occurred, thousands of drive bunches would be required to reach full gas ionization. This rapid rate of ionization was predicted by secondary ionization models and is key for scaling these types of devices to practical sizes. For a

3-mm interaction length, we measured decelerating gradients of 60 MV/m, which indicated accelerating gradients at least as large as 120 MV/m.

3.1.5 Linac Coherent Light Source and Free-Electron Laser

The DOE recently funded an R&D program to support the construction of the LCLS , a new x-ray FEL, at the SLAC. This new device will use the SLAC linear accelerator and a long undulator to produce sub-picosecond pulses of short-wavelength x-rays with very high-peak brightness and full transverse coherence for scientific applications. The basic method for generating coherent x-rays is based on a new, high-gain, free-electron laser (FEL) concept called self-amplified spontaneous emission (SASE). SASE uses no mirror but relies on beam guiding in a long undulator to amplify spontaneous noise all the way to saturation. LANL is working closely with SLAC, the University of California at Los Angeles (UCLA), and other DOE laboratories to develop a high-brightness electron accelerator and to demonstrate the basic SASE physics at infrared wavelengths.

The required electron-beam rms emittance for the LCLS design is 1 µm (mm-mrad) at a bunch charge of 1 nC. The first demonstration of a low-emittance, high-brightness electron beam at the level very close to the LCLS design had been done during the commissioning of the Advanced FEL at LANL. In that experiment, we measured an rms emittance of 2 for a 17-MeV electron beam at a bunch charge of 1 nC. In a series of follow-up experiments that culminated in his Ph.D. thesis, Stephen Gierman made the first careful measurements of the "slice" emittance on the Advanced FEL electron beams with sufficient resolution to show the dynamic behaviors of the 7-ps slices of the bunch. His measurements indicated that the slice emittance of the Advanced FEL electron beam is much closer to 1.5 µm for the middle slices, increasing toward the ends of the electron bunch. These careful measurements point the way to improving the slice emittance by using, for example, a higher-accelerating gradient and smaller photoemission area. We anticipate that the slice emittance is an important beam property that is much more applicable to the LCLS design.

The first demonstration of very high SASE gains in the infrared at LANL was achieved using the Advanced FEL's high-brightness electron beams and an undulator with an effective length of 1 m. Subsequent experiments performed at LANL in collaboration with UCLA and SLAC used the same electron beam but with a 2-m undulator that was built at UCLA. These later experiments achieved a single-pass gain at 12 µm of 3×10^5, the highest single-pass gain ever achieved in the infrared. Last year, LANL and UCLA also demonstrated the physics of FEL-electron-beam microbunching. After they interact with the FEL, the electron beams develop longitudinal microbunching on the scale of the infrared wavelength. In this experiment, we inserted a thin aluminum foil at the end of the undulator. The optical transition radiation emitted from the microbunched electron beams striking the thin aluminum foil exhibited a strong forward cone of coherent transition radiation at nearly the SASE wavelength. These SASE experimental results validate the physics of this new high-gain FEL and demonstrate for the first time excellent agreements between theoretical predictions and experimental measurements of exponential dependence of power on current, optical gain guiding in the undulator, pulse-to-pulse amplitude fluctuations, and electron microbunching at an infrared wavelength. These high-gain SASE experiments also culminated in Ph.D. theses for two UCLA graduate students. Go to *http://lansce.lanl.gov/research/accelerators/sheffield.htm* for more information on this subject.

3.1.6 PSR rf Buncher

Bunching is required in the LANSCE PSR to control momentum spread of the circulating beam and to maintain a gap free of protons for the extraction kicker to function properly. Beginning in 1997, the LANSCE rf team made improvements to the buncher to extend the ability of the system to operate at higher voltage with complete stability. The gap-voltage capability of the system was raised 33%, and the stability was substantially improved. In early FY99, the upgraded system became operational and the PSR was tuned to operate at 100 µA with acceptable losses for the first time.

In January 1999, we performed a series of experiments to determine if a pseudo-barrier waveform would significantly alter the threshold of instability. We modified the rf to provide both 2.8 MHz and 5.6 MHz in a controlled phase relationship to generate the desired barrier voltage waveform. These tests demonstrated that a single-frequency, 18-kV, 2.8-MHz rf buncher was adequate for desired beam intensities at PSR. Further tests demonstrated that passive ferrite inductive inserts would assist in the compensation of longitudinal space-charge effects. The rf buncher now operates routinely up to 18 kV with high reliability and excellent stability.

3.1.7 The EPICS Collaboration and Toolkit Continues to Expand

The LANSCE-developed control-system toolkit EPICS (Experimental Physics and Industrial Control System) continues to be a leader in the field of control systems for accelerators, telescopes, and other large scientific instruments. It is now licensed to over 110 scientific and educational institutions worldwide and is being extended at many of these laboratories in collaboration with LANSCE and ANL. In the past year, KEK-B, PEPII, ISAC, and BESSY were among the new facilities commissioned using EPICS. All are reporting success. Three new projects have baselined their systems on EPICS: Japanese Hadron Facility, the SNS, and the NLC. Some SNS partner laboratories recently unfamiliar with EPICS have successfully delivered working EPICS systems.

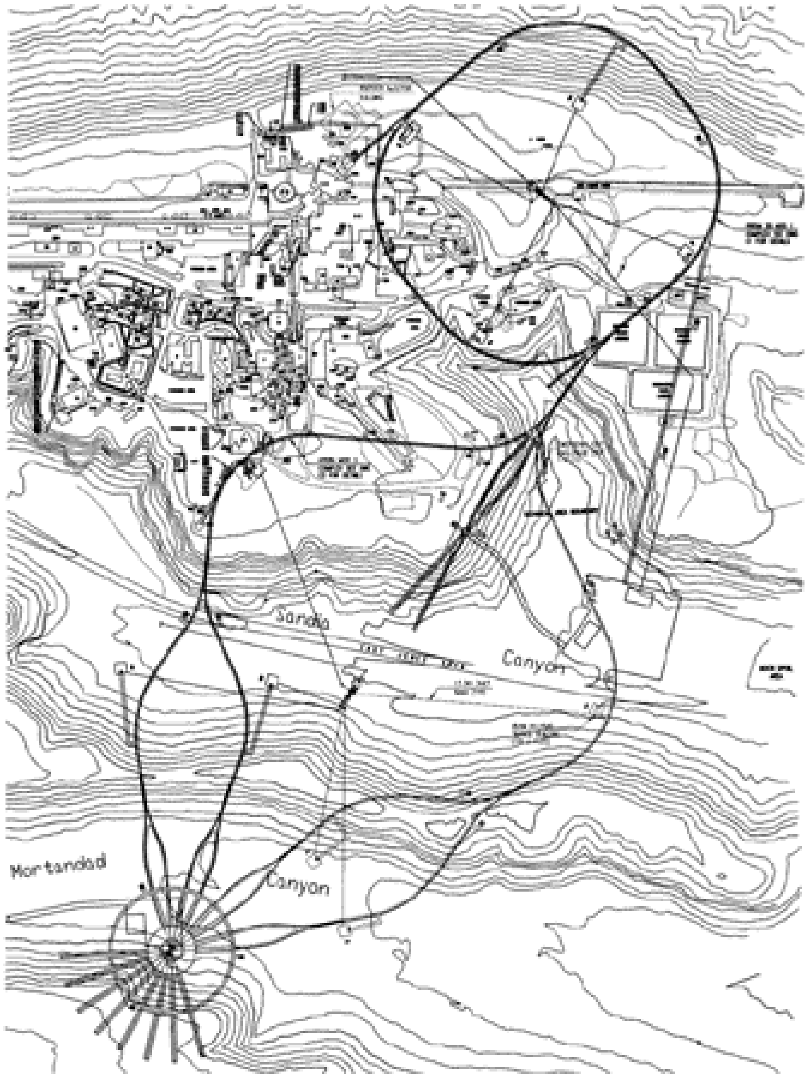
EPICS toolkit functionality continues to grow. The most basic function that had been missing was the ability to archive data for extended periods of facility operation. As part of the LEDA project, the first release of an improved archiver was made. Support for the PC as a control system platform advanced significantly over the last year. New extensions to the sequencer were produced, and there has been a great deal of support for a variety of graphic user interfaces. Work at the input-output level has focused on making the EPICS database portable to other operating systems. Finally, the portable channel-access server developed last year has been put into service to integrate existing commercial packages, such as Labview, Active X, and IDL with EPICS (see Section 3.3.7, *Digital Design Tools and Technology for Beam Diagnostics Electronics*, for a more detailed description of these improvements).

Under the leadership of LANSCE, the EPICS collaboration has agreed on a strategy and timetable for future EPICS developments, including an upgrade to the EPICS communication protocol for improved bandwidth and functionality, a port of the EPICS core to other operating systems to make the toolkit more attractive to a wider variety of users, and a unification of EPICS tools for improved inter-operability. For more information on EPICS, go to *http://lansce.lanl.gov/research/accelerators/gurd.htm.*

3.2 Accelerator Projects

3.2.1 Advanced Hydrodynamic Facility

This year LANSCE, working in collaboration with scientists from P Division and other laboratories, has prepared the preliminary design for a proposed new proton-radiography accelerator facility for LANL and the nation—the AHF (see Figure 40 and visit the web site *http://lansce.lanl.gov/news/features/domenici.htm*). This planned facility consists of a 50-GeV proton synchrotron constructed in a tunnel 350 ft below the LANSCE linear accelerator and an array of transport lines to supply proton pulses to a set of large-aperture magnetic lenses that illuminate and image dynamic test objects. The linear accelerator beam is bent into a vertical shaft to descend 109 m to inject into the synchrotron. The first phase of the project is to build the synchrotron and two imaging systems arranged to record a twenty-two frame stereo movie of a dynamic object. In a major follow-on upgrade project, a new target facility with full containment and twelve large imaging systems will be built. An extensive system of transport lines has been designed to carry proton pulses from the synchrotron to the new target area. AHF design personnel have provided the overall layout, beam optics analysis, and hardware concepts for the entire facility—from the synchrotron, injection and extraction lines, and beam distribution system to the large quadrupole imaging systems in the experimental area.



▲ **FIGURE 40**. *Drawing of the eight-beam-line AHF facility extending over 1 km from the end of the LANSCE linear accelerator (upper left).*

In the first phase of a proton-radiography-based AHF sited at LANL, the existing 800-MeV LANSCE linear accelerator would inject H^- ions directly into a 50-GeV synchrotron. The 50-GeV proton beam would be extracted from the ring at one location and then split into two beams. The two beams would then be transported to the test area by a pair of achromatic isochronous (equal-length) beam lines and illuminate the test object from two view angles. In later phases of the project, a booster synchrotron would be added to raise the synchrotron injection energy to 3 GeV. Also, a new beam-delivery system and test area would be constructed. There would be eight to twelve illuminating and imaging lines in the final system, and the incoming angles would be uniformly distributed over an arc of 158° or 165°, respectively.

Preliminary studies have consistently shown that the most cost-effective and operationally flexible approach to providing multiple synchronous illuminating lines is to extract the beam from the synchrotron at one location and to use staged binary splitting with bilaterally symmetric pairs of achromatic bends at every stage. Because of site constraints (the minimum-cost layout may not fit on the available real estate), other configurations may have to be considered, including "four-way splitting sections" in which the beam is first split horizontally and then vertically in one splitter section. In this class of configurations, the total length of the splitting sections is reduced, but the number of bending dipoles and straight sections in the beam lines increases.

Ongoing work includes construction of computer programs to perform rapid evaluation and graphics display of various beam-line configurations and input to cost-evaluation spreadsheets, beam-line optics programs, and drafting programs. Aside from cost, peak-power consumption is an important issue; the large amount of power required, especially by the lens magnets, cannot be supplied by the electrical grid. Hence, energy-storage devices and superconducting magnets are being considered and costed.

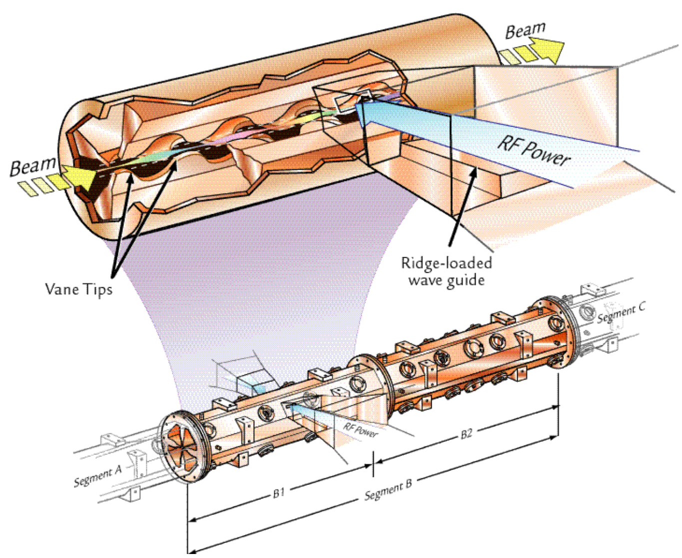
3.2.2 Accelerator Production of Tritium

3.2.2.1 Operation of the Low-Energy Demonstration Accelerator RFQ at Full Power

The Low-Energy Demonstration Accelerator (LEDA) rf quadrupole (RFQ) (Figure 41) has now been tested at full power. The LEDA RFQ successfully accelerated a 100-mA continuous wave (CW) proton beam to 6.7 MeV on September 16 and 17, 1999. Peak currents of 110 mA pulsed at 20% duty factor were also attained. This accelerator was built to provide experience with the front end of the APT project. LEDA was built at LANL collaboratively with APT, ESA, and LANSCE and with the help of Burns and Roe, General Atomics, Westinghouse Savannah River Corporation, and LLNL. In particular, LANSCE provided the RFQ structure, beam diagnostics, and commissioning personnel.

A number of technical challenges were overcome along the way in commissioning LEDA. In January 1999, while rf conditioning the RFQ with two klystrons, the rf-coupling irises melted at full CW rf power levels. Therefore, for the first experiments with beam, we operated with pulsed rf and beam. (Even at low duty factors less than 2.5% with 70-mA peak beam currents, the beam power with these first experiments exceeded 11 kW.) We redesigned the irises to eliminate the hot spots and reduced the number of rf waveguide feeds from twelve to six at the same time. After those first experiments with beam, we installed the new irises in May with two waveguides from each of three klystrons.

In September, we increased the beam current to 110-mA pulsed and over 100-mA CW for short periods of time. The 100-mA beam was obtained with all three low-energy beam transport (LEBT) collimators withdrawn from the beam axis (i.e., no collimation). Without the collimators, the transmission dropped below 90% with 100 mA accelerated. With such relatively poor transmission, the RFQ vacuum rose too high for extended runs. Modifications planned for the LEBT should increase the RFQ transmission and permit operation at 100-mA CW for extended periods. With the largest collimator in place in the LEBT, we have operated the LEDA RFQ at currents up to 90 mA CW with 95% transmission for uninterrupted periods as long as 30 minutes.



▲ **FIGURE 41.** *Artist's rendering of the LEDA. A solenoid magnet (not shown) focuses beam from the ion source into the low-energy end (Segment A) of the RFQ. As the beam travels through the RFQ gaining energy, the vane-tip modulation wavelength becomes longer. Radio-frequency power enters the RFQ at Section B1 (and D1) through small slots, known as irises, which are located between the ridge-loaded waveguides and the RFQ. The rf electric field accelerates and focuses the beam as it travels through the RFQ.*

3.2.2.2 Development of a 700-MHz Klystron for the Accelerator Production of Tritium Program

The APT program required the development of a 700-MHz klystron. We wanted to maximize the output power from the klystron to lower accelerator costs, and it was essential to provide a very high-efficiency tube to minimize operating cost. In addition, the APT program schedule mandated a very low technical risk for the development. Potential vendors were surveyed to determine the optimal set of operating parameters for the tube. We decided on a specification of 1-MW CW output power at a direct current (DC) to rf conversion efficiency of greater than 65%, a maximum operating voltage of 95 kV, and a beam current on the order of 16 A (the exact value depends on the operating voltage). Our klystrons are required to dissipate the full beam power in the collector, which allows the facility to minimize impact to the local utility grid when the accelerator beam turns on and off. We also required a modulating anode so the klystrons could be adjusted to provide maximum efficiency at operating voltages below design.

To lower technical and schedule risk, two klystron vendors, English Electric Valve (EEV) and Communication and Power Industries (CPI), were selected for the development. We initially purchased a single tube from each vendor. Both delivered a klystron that met all requirements. The EEV klystron operated at 95 kV and demonstrated an efficiency of 65%. The CPI klystron operated at 92 kV and demonstrated an efficiency of 67%. Both of these klystrons have five fundamental mode cavities and a single second-harmonic cavity. Both also use coaxial, high-purity alumina rf windows. EEV approached us after the development of their klystron with a proposal to attempt to provide even a higher efficiency klystron that involved using some of their internal funding. We purchased a second tube from EEV, and they attempted to design a second second-harmonic cavity to further improve efficiency. They were able to increase the efficiency to 67% but did not meet their 70% design goal.

3.2.2.3 Planned Experiment to Measure Beam Halo on the Low-Energy Demonstration Accelerator

A collaboration between APT and LANSCE determined that it would be useful to study aspects of beam-halo generation and verification of simulation codes. Unfortunately, the experiments planned in 1999 at Saclay in France using their injector accelerator were abandoned when the building housing the accelerator components collapsed. LANSCE provided the theoretical simulations and determined a possible lattice for performing significant beam-halo studies using the LEDA accelerator beam.

As a result of nearly a decade of theoretical studies, we believe that the beam-halo formation in the APT linear accelerator is caused by space-charge forces acting in a mismatched beam in a beam transport line or an accelerator. Beam mismatch produces an imbalance, which then induces beam-density oscillations that can resonantly drive particles to large amplitudes. Beam matching cannot be done perfectly; therefore, some halo is always expected. To establish a firm experimental basis to support the theory, we plan to conduct an experiment using a 24-period quadrupole-focusing lattice that will be installed after the LEDA RFQ. In this experiment, we will inject a mismatched beam into the focusing lattice and measure the generation of beam halo using three different types of beam-profile diagnostics, gas fluorescence devices, graphite jaws, and a phosphor screen. The measurements will be compared to theory and multiparticle simulations of a detailed and realistic model of the focusing lattice.

The purpose of the experiment is twofold: (1) to test and confirm the predictions of theory and multiparticle simulations of beam halo caused by beam mismatch, and (2) to explore with greater sensitivity the tails of the beam for possible additional sources of beam halo that are not predicted by theory or simulation code. We have carried out multiparticle simulations that show a very strong and easily measurable halo signal. The simulations show that we can produce a strong beam-halo signal by introducing mismatches through the adjustment of gradients of the first two quadrupoles of the focusing lattice. The simulations demonstrate the feasibility of the experiment. The concept of the experiment has been endorsed by the APT External Review Committee and will begin in October 2000.

3.2.2.4 Accelerator Production of Tritium Materials Irradiations and Results

The APT project conducted an extensive materials irradiation program at the Area A beamstop from 1996 to 1997. Extensive analysis of the samples from that program is ongoing at the Chemistry and Metallurgy Research

Division's Wing 9 hot-cell facility, ORNL, Pacific Northwest National Laboratory (PNNL), and other collaborating laboratories. The original test was followed by a second irradiation in October and December 1998. The scope of the second irradiation was expanded from the first: it contained numerous small-scale mechanical test samples to meet the needs of the APT plant designers and a variety of more specific experiments.

Five in-beam sites are available at the A-6 beamstop, which see 1-mA 800-MeV protons (see Figure 42). In the 1998 irradiation, the first site was filled with mechanical test samples similar to the 1996-97 irradiation. The second site retained the original tungsten neutron source comprised of stainless steel-clad tungsten rods. The third site contained a new experiment designed to measure decay heat in a realistic accelerator setting immediately after beam shutdown. The rate at which the system heats from decaying radioisotopes upon a loss-of-coolant accident is needed for safety analysis in the APT plant. In Area A, a series of Inconel-clad tungsten rods were irradiated, and the thermal behavior of the system monitored by measuring the difference between the inlet and outlet cooling water temperatures for extended periods following beam shutdown. This was a difficult test with numerous corrections; however, our preliminary simulation results indicate about 10% agreement with the data.

The fourth site was filled with another new test, called the "Helium Loop" experiment. In the APT plant, effective removal of tritium from the helium-3 gas stream calls for a knowledge of what spallation products from irradiated-target-area structures are produced, how they enter the gas stream, and how they are transported along the gas system. Both an aluminum- and copper-coated stainless-steel water-cooled cylinder were placed in the proton beam, and helium-4 gas was circulated through the system. This gas was transported out of the target area and analyzed with germanium gamma detectors before and after a series of filters. A small model of the APT lead/blanket system was also placed above the gas canisters to determine its performance in a prototypic neutron environment. The water-cooling system of the helium Loop experiment was also subjected to extensive testing to determine how spallation products are transported and how they plate out on components. After the end of the irradiation, the cooling system itself was decontaminated with standard nuclear reactor

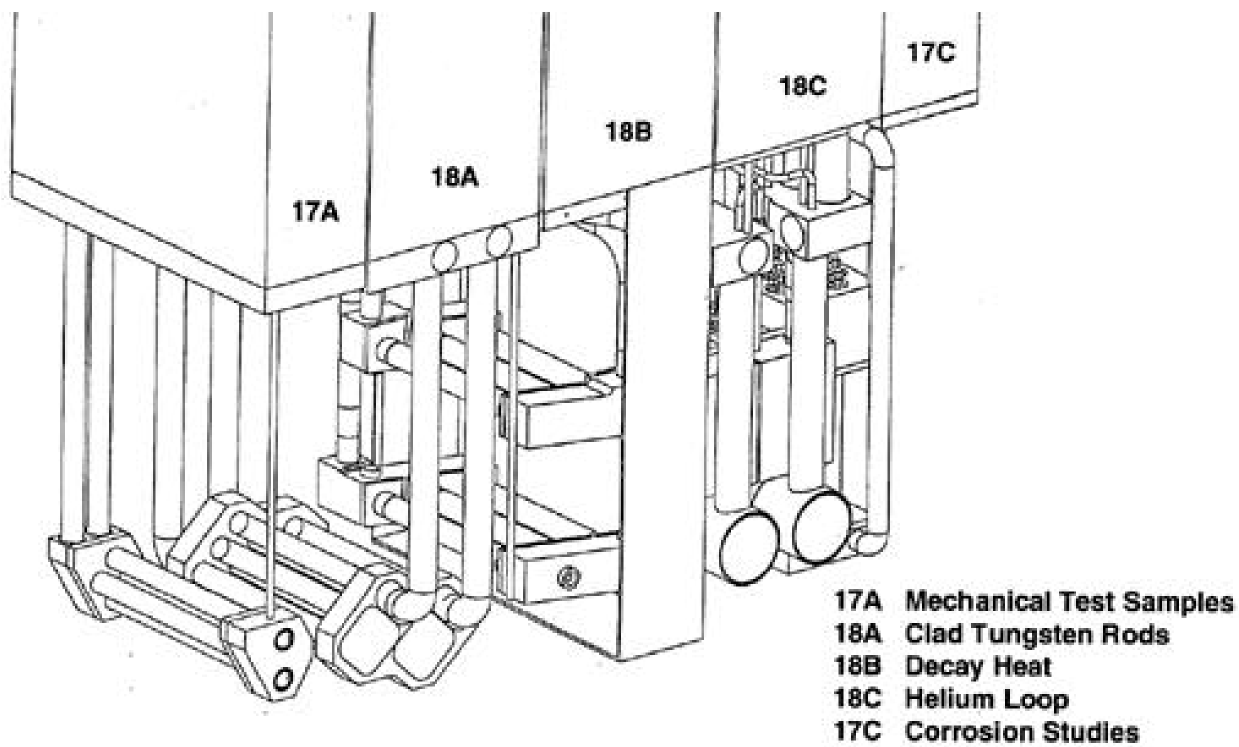


FIGURE 42. *Schematic diagram of the five in-beam inserts irradiated at the LANSCE beamstop from October through December 1998.*

methods, in our case, using PN Services' NITROX process. This represents the first time such a test had been done on an accelerator-related component where we dealt with beryllium-7 and sodium isotopes not normally present in reactors.

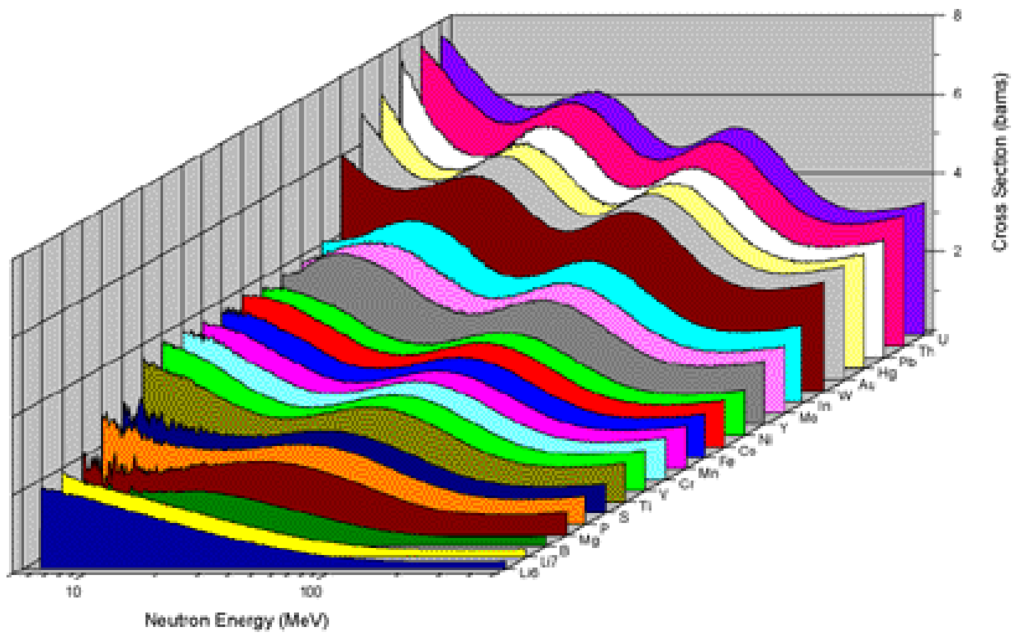
The fifth and last site was occupied by an on-line corrosion experiment, using the electrochemical impedance spectroscopy methods already tested in the 1996-97 irradiation. This test was run at a variety of beam currents and proton-beam energies and permitted immediate measurement of corrosion rates on a variety of materials in and out of the beam and above the insert before and after irradiation of the water. This irradiation was to have continued and other experiments implemented; however, the DOE tritium down-select decision has forced us to cancel future plans. However, we do hope to continue this work in the future, perhaps in collaboration with upcoming ATW or other programmatic work. Results from the APT irradiation program have been included in the APT Materials Handbook, the first such document ever written for a high-energy accelerator. The APT program has also made extensive use of other LANSCE facilities, fielding the following experiments:

- nonlinear beam transport (Area C);
- calorimetric measurement of decay-heat and energy-deposition measurements (Line B);
- neutron total cross-section measurements, tritium formation studies in neutron-irradiated water, and energy-deposition measurements in a water phantom (WNR); and
- corrosion studies, neutron production from heavy targets in water-bath experiments, tritium production studies in a semi-prototypic target, and stability of niobium superconducting cavities under irradiation (WNR Blue Room).

Much of this work was done to benchmark the new APT-sponsored MCNPX Monte Carlo simulation code and nuclear-data-library development.

3.2.2.5 Total Cross Sections on Materials Associated with the Accelerator Production of Tritium Project

Los Alamos has completed analysis of neutron total cross-section measurements of 36 materials from hydrogen to uranium and produced cross sections accurate to better than 1% for most of the materials over the neutron energy range from 5 to 600 MeV (Figure 43). These measurements were made at WNR in good geometry with



▲ **FIGURE 43**. *Results for 22 of the 36 samples measured.*

time-of-flight techniques using the sub-nanosecond source pulse. The materials included separated isotopes and other materials available only in small quantities. The accuracy sets a new standard in the state-of-the-art for these measurements. The energy range far exceeds that of any previous measurements with the exception of a previous measurement at WNR.

Neutron total cross sections are required by the APT program in two areas. First, the data are used directly in the preparation of data bases for neutron transport. The development of the MCNPX code, sponsored by APT, requires these data. MCNPX extends the capability of Monte Carlo neutron transport codes from the thermal to 20-MeV region, where they traditionally have been used, to the thermal to 150-MeV region important for APT. Previously, transport in the 20- to 150-MeV region and higher was modeled with cross sections calculated through nuclear models imbedded in the code. These models are known to have errors in the 20- to 150-MeV region and therefore the extension of data-base-oriented codes to this region was a high priority for APT. The total cross section is the sum of all of the partial reaction and scattering cross sections and therefore tightly constrains the evaluation of these other quantities.

The other application important for APT is in the development of an improved "optical model" (also known as the "cloudy crystal ball model") for describing the interaction of a neutron with a nucleus. T-2 is the principal engine for this theoretical development. When the neutron is absorbed by a nucleus, the system can decay into different channels described by reaction models. Accurate neutron total cross sections measured over the neutron energy range not only give the total interaction probability but they are also good guides as to the probability that the neutron is absorbed by the nucleus. The key here is the very high accuracy that could be obtained in these measurements.

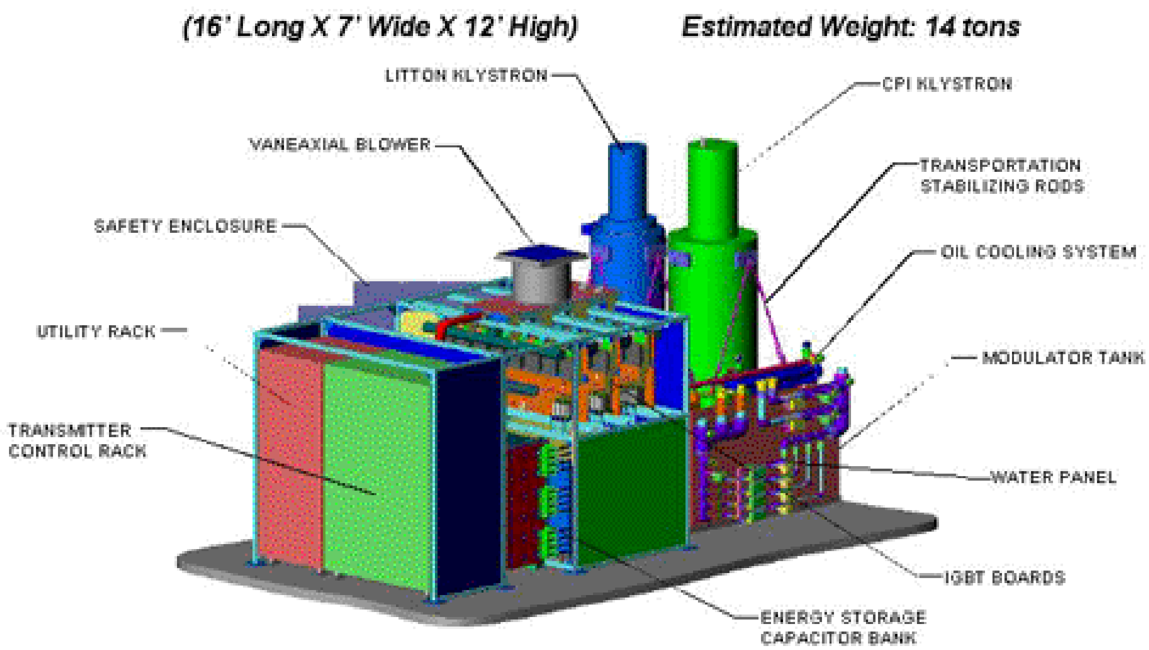
In addition to the applications to APT, these measurements are of great interest also to the basic science community. The neutron total cross section of light nuclei has shed light on the importance of relativistic corrections in few-body calculations based on the fundamental nucleon-nucleon interaction. Here the "optical model" can be calculated in principle from the basic nucleon-nucleon interaction. We found significant deficiencies in the calculations if relativistic effects were neglected. For heavier nuclei, the major question is the effect of the nuclear medium on the neutron interaction with nucleons in the nucleus—that is, do nucleons in the nucleus behave like free nucleons? Clearly they do not, and it is important to quantify these differences, which then can be addressed by higher-order theories. A paper is in preparation on this subject.

3.2.3 Spallation Neutron Source

The SNS is a collaborative effort of five national laboratories to build a next-generation neutron-scattering research facility at ORNL. Because of its long experience with designing and operating high-power accelerators, LANL was asked to deliver the 1-GeV, 1-MW H^- linear accelerator as a member of the collaboration. LANSCE Division provided personnel and leadership during the conceptual design, proposal preparation, design reviews, and initial R&D phases, which culminated in congressional funding for SNS construction beginning in FY99. During FY99, the budget and priority of the SNS project increased dramatically, and LANSCE hired a project director to lead the effort. Subsequent changes in project management and direction at ORNL resulted in a thorough reassessment of SNS technical options and design parameters in which we strongly participated. The results of this reassessment confirmed most of the technical choices but recommended increasing the beam power to 2 MW and taking several steps to increase project cost and schedule contingencies. These changes were incorporated for a DOE review of the project baseline in July 1999.

As part of the re-evaluation, Los Alamos investigated the advantages of using superconducting cavities for the high-energy part of the SNS accelerator—an option that had previously been examined and rejected by the collaboration and DOE reviewers. However, based on recent international superconductivity technology development and LANSCE Division's R&D efforts for the APT project, we were able to present a design for an SC option for SNS that is now being studied for cost and schedule impacts. In the meantime, the baseline design is being vigorously pursued with R&D on cold and hot models for the coupled-cavity structures, insulated-gate-bipolar-transistor (IGBT) converter-modulator development for the rf system, fast-chopper development, and beam-dynamics calculations using advanced codes developed by LANSCE. To focus the project effort at LANL, the Laboratory Director formed a separate SNS Division in August 1999, and LANSCE has helped to staff SNS Division with experienced accelerator physicists and engineers. In addition, LANSCE-8 is providing leadership and resources to manage the SNS control system using the EPICS computer technology.

3.2.3.1 The Insulator-Gate-Bipolar-Transistor-Based Converter-Modulator for the Spallation Neutron Source
LANSCE has been developing a novel high-voltage system for use on the SNS program. SNS is a pulsed accelerator (1-ms pulse width at 60 Hz). Typically, pulsed high-voltage systems use one unit (a converter) to convert the input alternating current (AC) power to high-voltage DC, and this high-voltage DC energy is stored in a capacitor bank for use during the pulse. The stored energy is pulsed into the load (a high-power rf tube in this case) with a modulator system. The SNS converter-modulator (Figure 44) uses modern IGBTs as a key element to combine the AC to DC conversion and storage with the modulator. The converter-modulator uses the fast, high-current switching properties of the IGBT to do the conversion and modulation at high frequency (approximately 20 kHz). This technique allows the transformers to be small and the stored energy to be low. The low stored energy eliminates the need for a crowbar or something similar to protect the klystron in case of a high-voltage fault in the tube. In the case of a tube fault, the fault current is low, and the fast switching properties of the IGBTs shut down the supply fast enough to avoid any follow-through current. This technology will be an important development for SNS and for future pulsed-accelerator rf systems.



▲ **FIGURE 44**. *Artist's rendering of the SNS converter-moderator assembly.*

3.2.4 Accelerator-Driven Transmutation of Waste

During the road-mapping activities in support of the national ATW program studies, LANSCE provided some accelerator expertise relevant to various accelerator scenarios and the technology development program needed over the next five years. The accelerator technology development program focus was on reliability and availability of CW accelerator systems, superconducting accelerating cavities, rf system optimization, and long-term performance of components for accelerators.

3.3 Accelerator Technology

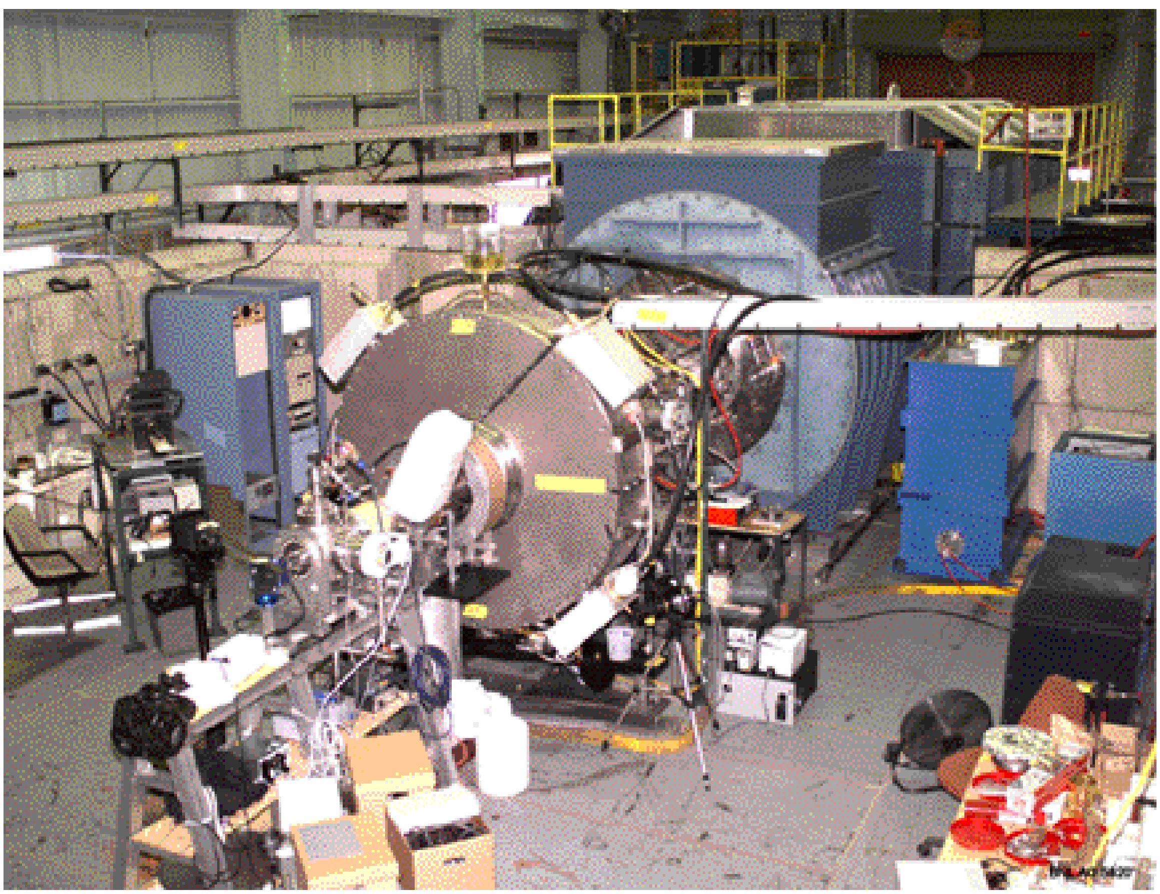
3.3.1 LANSCE 201-MHz rf Upgrade

The continuing reliability and availability of the rf power tubes used in the 201-MHz section of the LANSCE accelerator pose an appreciable risk to the future operation of the facility. The 201-MHz rf upgrade project has been undertaken to moderate this risk. Excellent replacement tubes for the final power amplifier (FPA) and the intermediate power amplifier (IPA) have recently been developed by Thomson Tubes Electroniques. The availability of desirable replacement tubes has fostered the 201-MHz upgrade project within LANSCE.

The first phase goal of the project has been to develop the amplifier cavity circuits for the TH628 (FPA Tube) and for the TH781 (IPA Tube). During 1999, the electrical design for both cavity circuits was completed. The mechanical design and parts fabrication for the FPA cavity circuit is 70% complete, and the fabrication and assembly of the FPA cavity circuit will be completed by the end of June 2000. One TH628 has been purchased and delivered to LANSCE. All utilities, power supplies, and rf loads for testing of both amplifiers have been acquired and are in place in the designated test-stand area of MPF-2.

3.3.2 THOR: The Long-Pulse Technology Development Facility

The Long-Pulse Technology Development Facility (THOR) was constructed to support the Laboratory's hydrotest program (Figure 45). The second axis of the Dual-Axis Radiographic Hydrotest (DARHT) facility is a



▲ **FIGURE 45**. *THOR Marx tank, diode, beam line, and 14 prototype injector cell.*

long-pulse induction electron accelerator. A long-pulse accelerator of this type has never been built before, and THOR is meant to study long-pulse beam physics, long-pulse diagnostics development, and long-pulse component prototyping. THOR is managed and operated by LANSCE personnel with help from Bechtel-Nevada and CST, DX, and ESA Divisions.

During this last year, THOR tested the first two long-pulse induction cells built for DARHT and demonstrated the first-ever long-pulse induction acceleration, thus providing the only available long-pulse beam until the DARHT second-axis accelerator is commissioned several years from now. These cells were evaluated for operational integrity and robustness. The effect on the beam dynamics as a cell arced was measured and studied. Several types of long-pulse diagnostics were fielded at THOR by LANSCE, DX, and P Division personnel. The most important diagnostic successes were the long-pulse demonstration of large-bore beam-bugs; the development of electro-optical beam-position monitors (using Cherenkov radiation from either slightly conductive intercepting-quartz screens or thin fibers); and the benchmarking of beam-bug and Cherenkov-screen total-current data to a Faraday cup. In addition, the large-bore beam bugs were shown to be insensitive to errors induced by the fields in the induction cells.

3.3.3 Cathode Test Stand

The Cathode Test Stand (CTS) is a new LANSCE facility that does research on large thermionic electron guns, primarily in support of the DARHT project. The DARHT second-axis (DARHT-2) requires a 3.2-MV, 2-kA, 2-μs injector. The injector will use a 6.5-in.-diam thermionic dispenser cathode. Because such a cathode has requirements far exceeding existing cathode assemblies, the CTS is used for measuring the electron gun's most important engineering features. The cathode is tested *in situ* as part of an operational electron gun that has most of the design features envisioned for the DARHT-2 injector. The CTS is a small but versatile facility for characterizing cathodes and electron guns. The CTS consists of a 500-kV, 1-μs modulator; an ultra-high vacuum (10^{-10} Torr) tank; and a short beam line (to be constructed soon).

During the past year we constructed the facility and completed a careful characterization of the thermal properties of an 8-in.-diam cathode. We used more than a dozen thermocouples to measure the thermal properties of the cathode support assembly. We developed a new technique for measuring cathode emissivity, which is important because it determines the heater power required to obtain the 1050°C operating temperature. We also developed a method for mapping the temperature of the cathode surface with a spatial resolution of 2 mm and a temperature resolution of 4°C. These are important measurements because they affect the cathode lifetime, current emission, and electron-beam quality. During the past several months, we have designed and fabricated a current-emission diagnostic. With this diagnostic, we can measure how the current emission varies over the surface of the cathode. Achieving uniform current emission is critical for meeting the DARHT requirements on beam emittance and spot size. We will look for correlation between emission variation and emissivity and/or temperature variations.

3.3.4 Development of Air-Core, High-Voltage Pulse Transformers

A common need exists for compact, pulsed power systems for high-power microwave sources. These microwave systems use both advanced, conventional modulator technology and explosively driven flux-compression generators as the power sources. Both require impedance transformation to step up the voltage to the necessary level required to drive the microwave source. We began developing a compact, air-core pulse transformers capable of driving microwave sources from either conventional or explosive pulsed-power sources. These transformers need to be capable of outputs of up to 500 kV and currents up to 200 kA with a very high coupling efficiency and low leakage inductance. A set of fabricated transformers used a novel single-turn coaxial-can configuration for the primary winding. This configuration led to a very high coupling efficiency of greater than 0.9 for an air-core design. These transformers have delivered in excess of 100 kA to a load at voltages of between 100-200 kV. The primary input current for the transformer in this case was 6 MA and was driven from an explosive flux compressor. Breakdown between the primary and secondary is currently the limiting factor of these transformers. The current effort is to increase the output voltage to approximately 300 kV by increasing the primary to secondary insulation.

3.3.5 Beam Dynamics in Linear Induction Accelerators

A study to understand long-term emittance evolution in high-brightness induction linear accelerators was completed by LANSCE beam physicists. This study was important in understanding the overall beam physics in the DARHT-project accelerators. Early in the accelerators, the beam dynamics and emittance evolution is dominated by coherent transverse plasma oscillations. These oscillations are initiated by focusing nonlinearities in the electron diodes. These nonlinearities lead to both an initial curvature of the beam's phase space (emittance growth) and also a non-uniform beam density. The beam then executes transverse plasma oscillations as it is both accelerated and focused. The oscillations lead to the phase-space curvature, changing sign back and forth as the curvature is coupled to the beam-density profile. Fortunately, particles at different radial locations within the beam stay in phase during this process. (A secondary study showed that thermalization of these transverse oscillations resulting from the difference in oscillation frequency for different radial positions took several hundreds of meters of drift.) During these plasma oscillations, the emittance also oscillates from a very small value to a very large one. Ideally, we want to freeze the emittance at the low value, which can be done. As the beam is focused, a radial nonlinearity, caused by the radial work done on the electrons in the beam from the beam's own space charge, is introduced (even if the focusing force is purely linear). By phasing the plasma oscillations correctly, we can obtain a straight phase-space distribution and a uniform beam density profile as this effective nonlinear radial force works out the kinks in the beam's phase space. This procedure is the basis of the DARHT second axis tune.

The residual emittance that is left after this tuning procedure results from the wave breaking of the edge electrons in the focusing of the beam just after the diode. Particles at the outside of the beam, where the density drops to less than one-half of the average density within, will not see enough space-charge force to prevent them from entering the core of the distribution. These particles will then be attracted to the common 1:2 resonance, forming a beam halo and resulting in an emittance growth. The DARHT second axis tune also includes minimizing this wave breaking. Simulations of the DARHT first axis accelerator show a substantial amount of wave breaking for that machine; these simulations were confirmed by comparing them to experimental beam profile measurements. This study will lead to modifying the first axis tune to reduce the halo production and decrease the beam emittance.

3.3.6 Novel Diagnostics Development for High-Brightness Electron Accelerators

LANSCE has been developing diagnostics for high-brightness electron accelerators, both rf and induction linear accelerators. For the rf linear accelerators, a technique to measure the beam's rms size using beam position monitors (BPMs) was demonstrated. A BPM has four electric field probes located at 90° intervals around a section of beam pipe at a single axial position. As the electron beam travels through the aperture of the BPM, the probes sense the image charge that the beam induces in the metal walls of the beam pipe. By combining the four signals appropriately, the difference between the horizontal and vertical rms beam sizes can be found. Thus, by using a quadrupole channel in which the horizontal and vertical beam phase spaces are different, we can find both the horizontal and vertical emittances by inverting the transport matrices. The main technical difficulty was learning how to make this procedure numerically stable and to reduce the error associated with errors in the measurements. We accurately measured normalized emittances as low as 10 mm mrad. By coupling this measurement technique to an rf transversely deflecting cavity, we were also able to accurately measure the length of electron bunches to about 5 ps. We expect that a final resolution of about 500 fs is possible with this technique. One strength shared by both of these diagnostics is that they are non-intercepting.

Another novel non-intercepting technique that we developed uses the beam's induced axial diamagnetic field in a solenoid to measure the rms beam size of a beam in an induction linear accelerator. At the beam-pipe wall, the diamagnetic field is directly proportional to the beam size times a few well known and easily measured constants. The diamagnetic field is easily measured by integrating the signal from a loop inserted near the wall. Measurements were made of the THOR beam, although the data has not been adequately reduced to provide estimates of the accuracy of this technique. We can also measure the beam density uniformity by using two of these diagnostics.

3.3.7 Digital Design Tools and Technology for Beam Diagnostics Electronics

LEDA CW operations and stringent accuracy requirements demanded a new approach to beam diagnostics and thus have induced the adoption of hybrid digital beam diagnostics. CW operation eliminates the non-data-taking time between pulses. This interpulse interval was traditionally used for data reduction and transfer to the control system in low-duty-factor pulsed machines. LEDA diagnostics were envisioned as a data-processing pipeline that would supply a quasi-continuous stream of reduced, high-accuracy data. Also, LEDA's ambitious schedule required that seven distinct types of beam-diagnostic measurement systems be designed, tested, and integrated with the control system in a compressed time frame. More efficient electronic-system design techniques are needed, however, to field these measurement systems in time to support LEDA commissioning.

To meet the stringent accuracy requirements for the BPM, phase and energy, and beam-current diagnostics systems, we incorporated a hybrid analog-digital design into these systems that would accurately simulate the integrated performance of both the analog- and the digital-signal-processing sections. These sections include both field-programmable-gate-array (FPGA) hardware processing and digital-signal-processing (DSP) algorithms. We used a mixed-mode simulation software (System View by Elanix) to simulate these systems. The simulations allowed the system-level design for each measurement to be verified with a combination of realistic models of each signal-processing section (analog and digital). The accuracy of these models allowed each measurement system design to be optimized to meet LEDA's requirements while the short-design cycle time and reusable component models led to the development of a generic digital motherboard design that met the requirements for both the BPM and phase/energy measurements.

All the digital designs on the LEDA controls and diagnostics were implemented using an advanced hardware-logic definition language known as Very High Density Logic (VHDL). VHDL allows us to define digital designs in a generic fashion that is easily and transparently portable between designs, even between those that use different chip manufacturers. These logical designs can be organized into functional libraries that can be shared among many designs, speeding up design cycles by providing proven functional blocks. An additional advantage is the availability of simulators to test designs both logically and as implemented in each chip type. These advantages proved critical in fielding the LEDA controls and diagnostics designs since the schedule did not allow for iterative development. A measure of the improvement in design efficiency is a comparison with similar designs fielded during the Ground Test Accelerator (GTA) project. Although the digital portion of the LEDA designs represent a factor of at least ten times greater complexity (as measured in gate count) or two times greater (as measured in number of measurement system types), the labor required to design them was reduced by about 50%.

DSP support tools were used as an integral part of the BPM, phase and energy, and beam-current diagnostic systems. While the overall algorithms were developed using the mixed-mode simulation tool described above, efficient tools were also required to implement and verify the actual DSP code. To shorten the code-design cycle, we chose a commercial vendor to provide the DSP modules and the programming- and testing-support hardware. In addition, a powerful DSP code implementation and verification tool (Code Composer by GO-DSP) was used to create and test the run-time DSP code. These new digital-design tools enabled LANSCE to respond to the beam-diagnostics requirements of LEDA with greatly improved predictability and efficiency in the engineering process. LANSCE delivered designs that improved the performance of the beam diagnostics as demonstrated in LEDA operations. Furthermore, the hybrid analog/digital designs for LEDA have proven to be flexible and reusable. With small modifications, these basic beam diagnostic modules will be used to diagnose the beam halo experiments, and the digital tools and technology from LEDA is being used on the SNS beam-diagnostics system.

3.3.8 Improvements to the Experimental Physics and Industrial Control System

We have developed a new Experimental Physics and Industrial Control System (EPICS) archiver that can archive 10,000 data samples per second (as measured on a 450-MHz Pentium and a Sparc Station 5) to each of any number of running instances of the archiver program. It archives all native EPICS data types, as well as arrays of data types. Data retrieval for up to 1,000 samples taken within the last seven days takes less than one-tenth of a second. The archiver can run under Windows, UNIX, and LINUX. In addition, data retrieval tools are available under UNIX, Windows, and, by popular demand, through a Web browser interface. Support is being added for XY plots for vector and scalar data. We have improved the operation of the archiver by implementing a Web-based management process for the archiver and a "blind" archiver operation that allows the archiver to start up automatically or on reboot, thus eliminating the need for a window on the operator console. The archive data-taking and retrieval function allows different archive sources, so that other users with different data-taking engines can take advantage of the remainder of the code for the interface to EPICS real-time data and all retrieval tools.

There are also major changes occurring in the process database and channel-access protocol. Significant progress has been made toward creating a portable process database using the existing Channel Access server. (Channel Access is the EPICS communication protocol.) This improvement removes the previous constraint that the process interface software could be run only in a VxWorks environment. (VxWorks is the proprietary real-time operating system that current versions of EPICS run under.) With a portable database, channels that were created in input-output controllers (IOCs) to support the operator interface can be moved into the non-critical operator-interface module, allowing for more flexibility at the workstation and less complexity in the IOC. This change will also allow small sites to run EPICS without having to purchase a VxWorks license, which can take a large part of a small project's budget.

In 1999, we made plans to modify the EPICS Channel Access communication protocol and the distributed process database to improve performance, remove remaining limitations, and provide some services that have been missing. Plans include

- support for multi-master control of external hardware, such as programmable logic controllers;
- addition of multi-dimensional arrays;
- implementation of unlimited string lengths;
- periodic notification of changes;
- control over queuing strategies for channel access;
- establishment of multi-priority communication links;
- creation of a standard name server for resolving references; and
- protocol support for data over time and dynamic composite data.

These changes will result in better control over the performance and degradation modes of a control system. They will also provide a structure for the integration of higher-level applications that support data analysis and automation of demanding applications, such as particle accelerators. With the core EPICS collaborators, we have agreed on a strategy, task allocation, and timeline for the implementation of these improvements.

3.3.9 Superconducting Systems

LANSCE has continued to develop its capabilities in superconducting systems in collaboration with APT and ESA Division, as well as with participation of MST Division and LLNL personnel. The superconducting laboratory has been significantly upgraded to handle the testing and development required by APT. The clean room has been extended from 800 ft^2 to 2,600 ft^2 with half the area rated as Class 100 or better. This expansion provides space and utilities for cleaning and assembly of the 700-MHz, five-cell cavities; associated power couplers; and the large APT multi-cavity cryomodules. The laboratory's high-pressure-rinse systems have been upgraded and can provide 3 gal. of ultra-pure water per minute for cavity rinsing. The MST chemistry laboratory has been reworked to provide improved control of the chemical-polishing process. The cavity test area that contains two large vertical cryostats has been provided with a movable 8-in.-thick steel cover to shield the expected ionizing radiation from high-power testing. A large mezzanine structure for assembly of the cryostat inserts has also been constructed. Test electronics have been upgraded and the expanded control console has been moved to an adjoining room. Additionally, the laboratory's operational safety has been carefully assessed with extensive revisions to gas-flow systems, oxygen monitoring, and cryogen-transfer equipment and procedures. The laboratory's hazard control plan (HCP) and safety measures have been audited by DOE and were awarded a "noteworthy practice."

During the laboratory upgrade, cavity design and construction were pursued. Extensive design iteration resulted in fabrication of several (β=0.64) niobium cavities at LANL, by AES, and by CERCA in France. Final processing, tuning, and testing will be done at LANL and at Thomas Jefferson National Accelerator Facility (TJNAF). A tuning bench has been constructed in the LANSCE laboratory that is capable of tuning a wide range of cavity types. Initial shakedown of the cavity test facility and development of testing procedures was done with a one-cell cavity at 2 K. We will be ready to test the five-cell cavities in early 2000. Meanwhile, TJNAF, in a parallel testing effort, has verified the performance of one five-cell cavity.

In a parallel development, a prototype power coupler has been constructed and tested in a test stand. For the tests, two couplers are connected to an rf cavity with power fed to one coupler and removed from the second. The tests were successful with transmission of about 1 MW for several hours after a few hours of conditioning. Vacuum remained good and only one (weak) multipacting band was noted at low power. Commercial rf windows were also simultaneously tested with acceptable performance. Further testing will be done to show that the couplers will meet APT's requirement of a 300-kW power transmission under the more stringent conditions of low temperature and with beam.

In future work, the cavities will be tested at 2 K, and two cavities will be incorporated in a cryomodule for cold testing. Through this collaboration with APT, the LANSCE superconducting laboratory has become a fully functioning facility capable of developing other quality superconducting rf systems.

3.3.9.1 Pulsed-Superconducting Prototype Module

A large part of the future of high-intensity linear accelerators will involve superconducting rf structures. Despite this, high-intensity pulsed ion beams (as distinct from the simpler application to electron beams) have not been accelerated in superconducting linear accelerators. DESY laboratories in Germany have provided enough useful information on interactions with electron beams in pulsed superconducting systems to assist us in our ion-beam work. LANSCE has had extensive experience in the fabrication and testing of superconducting structures but has not performed tests with beam. To achieve a position of leadership, we must have experience with beam in our rf structures and experiment with the issues that arise for superconducting acceleration of pulsed ion beams. Such experiments would include the following.

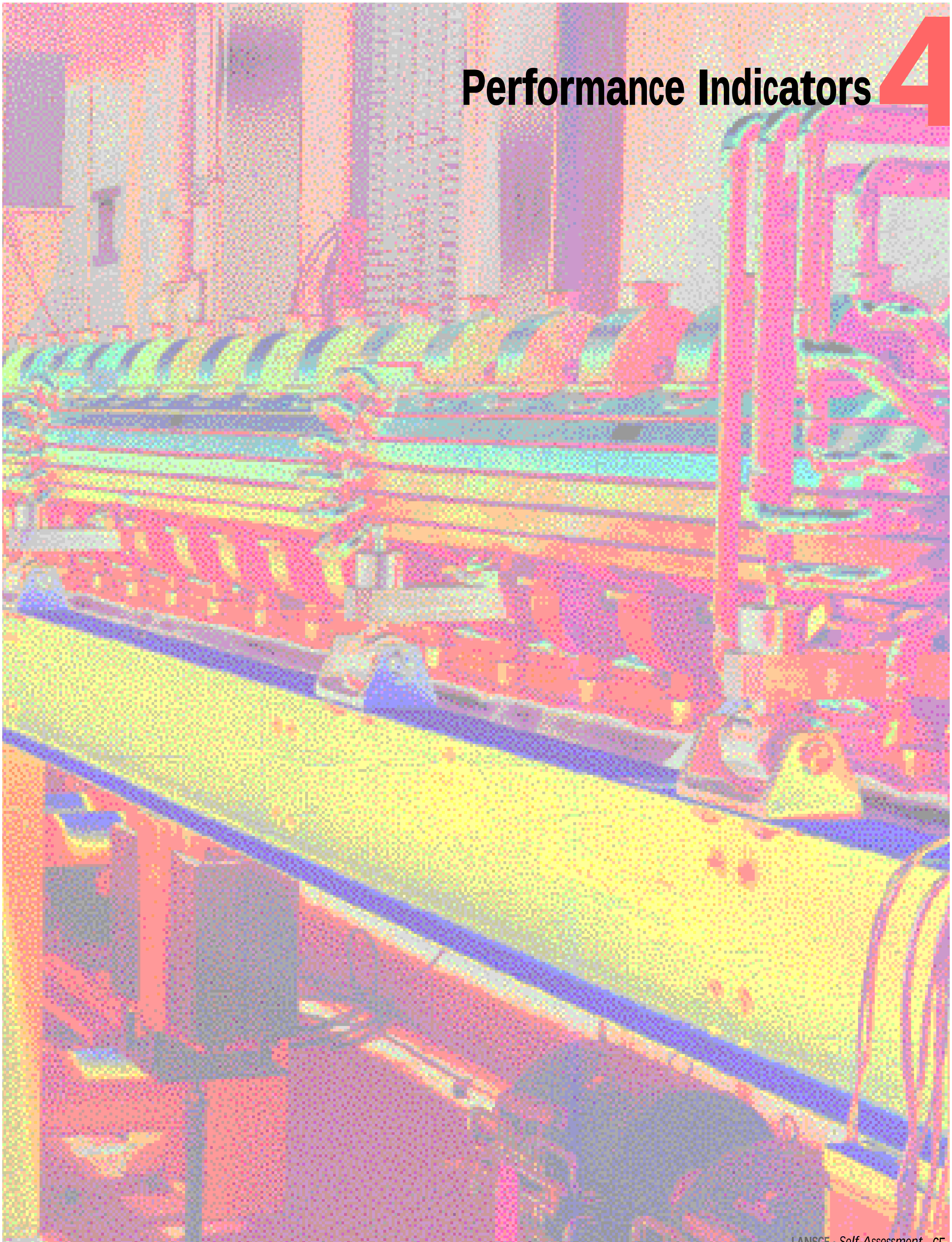
- **Effects of the mechanical impulse ("Lorentz forces") on the cavities during rf-power turn on.** As rf power is introduced at the start of each beam macropulse, the cavities experience an impulsive force. Fast active damping and cavity stiffening would be necessary with sophisticated rf control.
- **Microphonics.** Mechanical noise and beam-current fluctuations cause variations in the beam properties of superconducting cavities. Testing is needed to determine possible problems and to develop and gain experience with rf control using fast feed forward and other sophisticated feedback techniques.
- **Turn-on transients.** Large over- or under-shoots in the accelerating fields are predicted during beam-pulse turn-on that lead to intolerable beam-energy fluctuations. We need to evaluate rf control and coupling techniques.
- **Power couplers.** Radio-frequency energy must be fed into the cavities by an antenna-like device known as a power coupler. Problems with multipacting and power transmission are crucial issues that must be addressed to achieve high accelerating gradients with large beam intensities.

- **Higher-order modes.** The interaction of intense proton beams with the cavity will excite high-order resonant modes. The primary issue is whether the strength of the excited field is sufficient to lead to beam degradation. Although this problem has been evaluated with linear-accelerator beam transport codes, there is no experimental data for proton linear accelerators.

At LANSCE, we have perhaps the world's best beam source for experimental resolution of these issues, and we have requested institutional support to carry out a program to this effect. We would use an existing four-cell 805-MHz superconducting cavity that has removable stiffeners. A duplicate of this cavity would be needed to address the control issues. We would also design and fabricate a horizontal cryostat and power couplers, which would be mounted in the beam line leading to Area A, and a sophisticated rf system that would address the pulsed superconducting issues mainly on existing equipment. To minimize cost, we would use dewars of liquid helium to supply cryogen instead of a liquifier system.

This program would support institutional goals and further enhance LANL's technology base by creating a strong position to compete for new spallation sources or other projects that require the use of pulsed linear accelerators. In particular, there would be a strong basis for a LANSCE upgrade if an afterburner were implemented. Such an upgrade could readily maintain service to all present facilities (PSR, WNR, PRAD, and IPF) and would be enhanced by addition of a new front end incorporating an RFQ.

Performance Indicators 4



4 PERFORMANCE INDICATORS

4.1 Publications in Peer-Reviewed Journals

Refer to the list in Appendix A.

4.2 Publications in Conference Proceedings

Refer to the list in Appendix B.

4.3 Classified Reports

LANSCE Division had one classified report during this period. Refer to the list in Appendix C.

4.4 Awards, Honors, and Elections to National Science/Engineering Societies

Stan Brown (LANSCE-8): Los Alamos Achievement Award
Timothy Callaway (LANSCE-6): ES&H Worker Recognition, September 1999
B. E. Carlsten (LANSCE-9): 1999 US Particle Accelerator School Prize for Achievement in Accelerator Physics and Technology
Everett Espinoza (LANSCE-6): Certificate of Appreciation, August 1999
Michael P. Geelan (LANSCE-7): (1) Los Alamos Achievement Award for outstanding accomplishments and dedication; (2) 1999 Pollution Prevention Award
Jeffrey Hannaford (LANSCE-7): 1999 Pollution Prevention Award
Johnny Herrera (LANSCE-7): 1999 Pollution Prevention Award
Tonya Kuhl (University of California – Santa Barbara): Presidential Early Career Award from National Science and Technology Council
Janet Lovato (LANSCE-6): Certificate of Appreciation, August 1999
Kathy Lovell (LANSCE-12): Los Alamos Achievement Award
Matthew Lusk (LANSCE-6): Certificate of Appreciation, August 1999
Carlos Manzanares (LANSCE-6): Certificate of Appreciation, August 1999
F. Mezei (LANSCE-DO): (1) Inaugural Walter Haelg Award of the European Neutron Scattering Association (NSE) for being the most outstanding contributor to the progress in neutron scattering science in Europe in the past 3 decades; (2) Inaugural Eugene P. Wigner Award of the Hungarian Government and the Hungarian Academy of Sciences for the most outstanding contribution to physics achieved by a native Hungarian working abroad
Steve Morgan (LANSCE-7): 1999 Pollution Prevention Award
Filippo Neri (LANSCE-1): Award for Excellence for Nuclear Weapons
Peter Olivas (LANSCE-7): 1999 LANL Distinguished Performance Award
Margarita Russina (LANSCE-12): (1) ECNS '99 Young Scientists Award; (2) PhD-Preis (Promotionspreis) of Hahn-Meitner-Institite Berlin
Greg Smith (LANSCE-12): LANSCE Director's Award for Scientific Excellence, Los Alamos Achievement Award (go to *http://lansce.lanl.gov/news/features/director'saward.htm*)
Craig Stinson (LANSCE-6): ES&H Worker Recognition, September 1999
Robert B. Von Dreele (LANSCE-12): 1999 LANL Distinguished Performance Award (go to *http://lansce.lanl.gov/news/features/111099_vondreele.htm*)

4.5 Elevation to Fellow or Equivalent in Professional Organizations

Rob Robinson (LANSCE-12): Fellow, American Physical Society

4.6 Invited Talks and Presentations

Goetz M. Bendele (LANSCE-12), Instructor at the US Particle Accelerator School, May 1999, held at Argonne National Laboratory through the University of Chicago.

Donald W. Brown and Mark Bourke (LANSCE-12), "Applications of Rietveld Refinement to Engineering Problems," 48th Denver X-Ray Conference, Steamboat Springs, CO, August 2–6, 1999.

Luke L. Daemen (LANSCE-12), "Monte Carlo Tool for Neutron Optics and Neutron Scattering Instrument Design," 44th Annual SPIE Meeting, Denver, CO, July 19–23, 1999.

D. H. Fitzgerald (LANSCE-2), "Proton Storage Ring Injection Upgrade," ICFA Mini-Workshop on Injection and Extraction in High-Intensity Proton Machines, Abingdon, UK, February 23–26, 1999.

David Gurd (LANSCE-8), "Plans for a Collaboratively Developed Distributed Control System for the Spallation Neutron Source," PAC ’99, NY (1999) p.355 (Repeated with permission and by invitation at ICALEPCS ’99, Trieste, Italy).

Jeff Hill (LANSCE-8), "PC-Based Input/Output Controllers from a VME Perspective," PC/PAC ‘99, Tsukuba, Japan, January 12–15, 1999.

Axel Hoffmann (LANSCE-12), "Artificially Induced Reconfiguration of the Vortex Lattice in Nb," Superlattice and Microstructure Workshop, Cancun, Mexico, August 27–29, 1999.

Axel Hoffmann (LANSCE-12), "Periodic Pinning with Magnetic Dots: Does the Size and Geometry Matter?" 1999 Centennial Meeting of The American Physical Society, Atlanta, Georgia, March 20–26, 1999.

Frank Krawczyk (LANSCE-1), "Status of LANL Activities in RF Superconductivity," 9th Workshop on RF Superconductivity, Santa Fe, NM, November 1999, LA-UR 99-6595.

Rob Merl (LANSCE-12), "The Effect of Charge State on Fullerene Polymerization," 1999 Centennial Meeting of the American Physical Society, Atlanta, Georgia, March 20–26, 1999.

Ferenc Mezei (LANSCE–DO), "What Neutrons Do Tell Us About the Nature of (Spin) Glasses," ECNS ’99, Budapest, Hungary.

M. Plum (LANSCE-2), "Electrons in the PSR," LANSCE Short Pulse Spallation Source Buncher II TiN Workshop, Los Alamos, NM, May 17–18,1999.

M. Plum (LANSCE-2), "Experimental status of the PSR instability," LANSCE Short Pulse Spallation Source Buncher II Replanning / PSR Instability Workshop, Los Alamos, NM, January 19–20 1999.

M. Plum (LANSCE-2), "Status of the PSR Inductor," LANSCE Short Pulse Spallation Source Buncher II Replanning / PSR Instability Workshop, Los Alamos, NM, January 19–20, 1999.

M. Plum (LANSCE-2), "Status of the SREX Line," LANSCE Short Pulse Spallation Source Buncher II Replanning /PSR Instability Workshop, Los Alamos, NM, January 19–20, 1999.

Margarita Russina (LANSCE-12), "Beam Extraction and Low Losses Guides," Workshop NOP, Villigen, Switzerland, November 25–27, 1999.

R. Ryne (LANSCE-1), "Computational Challenges in High-Intensity Ion Beam Physics," 2nd ICFA Advanced Accelerator Workshop on the Physics of High-Brightness Beam, UCLA, November 1999.

R. Ryne and K. Ko (LANSCE-1), "Large-Scale Simulation in the Computational Accelerator Physics Community: Current Activities and Future Plans," presented to the High Energy Physics Advisory Panel, Gaithersburg, MD, October 1999.

T. Spickermann (LANSCE-2), "The Antiproton Decelerator Project," Los Alamos Neutron Science Center, Los Alamos, NM, May 1999.

T. P. Wangler (LANSCE-1), "APT Linac Design for Low Beam Loss," 7th ICFA Mini-Workshop on High Intensity High Brightness Beams—Beam Halo and Scraping, Lake Como, WI, September 13–15, 1999.

T. P. Wangler (LANSCE-1), "Beam Halo Formation in High Intensity Proton Beams," 2nd ICFA Advanced Accelerator Workshop on the Physics of High Brightness Beams, UCLA, November 9–12, 1999.

T. P. Wangler, K. R. Crandall, J. P. Kelley, F. Krawczyk, D. L. Schrage (LANSCE-1), **J. H. Billen, S. Nath** (SNS-PO), and **H.Padamsee** (APT-TPO) "Design of a Proton Superconducting Linac for a Neutron Spallation Source," 9th Workshop on RF Superconductivity, Santa Fe, NM, November 1–5, 1999.

4.7 Contributed Talks

H. N Bordallo, D. N. Argyriou, G. F. Strouse, and J. F. Mitchell, "Lattice Displacements Above T_c in the Layered CMR Manganite $La_{1.2}Sr_{1.8}Mn_2O_7$," *Bulletin of the American Physical Society* **44** (1), 1895 (1999).

B. J. Campbell, A. M. Dos Santos, J. M. Delgado, G. D. Diaz De Delgado, A. K. Cheetham, G. F. Strouse, D. N. Argyriou, H. N. Bordallo, and D. E. Cox, "Charge and Magnetic Ordering in the Ruddleson-Popper N-2 Manganate $LaSr_2Mn_2O_7$," *Bulletin of the American Physical Society* **44** (1), 1895 (1999).

S. C. Chang, H. Nakotte, H. N. Bordallo, M. S. Torikachvili, A. V. Andreev, and A. J. Schultz, "Structural and Magnetic Properties of U(T,Co)Al Solid Solutions," *Bulletin of the American Physical Society* **44** (2), 1221 (1999).

D. G. Enzer, A. J. Berglund, D. J. Berkeland, J. J. Gomez, M. S. Gulley, M. H. Holzscheiter, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, V. D. Sandberg, M. M. Schauer, D. Tupa, A. G. White, and R. J. Hughes, "Quantum Computation with Trapped Calcium Ions," *Bulletin of the American Physical Society* **44**, 1312 (1999).

J. Langenbrunner, J. S. Sarracino, D. L. Quintana, P. D. Ferguson, L. S. Waters, G. L. Morgan, F. H. Cverna, K. J. Adams, R. Liljestrand, E. C. Snow, R. G. Cooper, A. Whiteson, and A. Hanson, "Coupled Proton, Neutron, and Gamma-Ray Transport; Code Validation Technique and Application," *Bulletin of the American Physical Society* **44** (5), 79 (1999).

G. F. Strouse and H. N. Bordallo, "Analysis of the Lattice Mode of Vibrations in the Layered CMR $La_{1-2x}Sr_{1+2x}Mn_2O_7$," *Bulletin of the American Physical Society* **44** (1), 191 (1999).

M. S. Wechsler and D. J. Dudziak, "Radiation Damage to Materials at Spallation Neutron Sources (SNSs)," *Bulletin of the American Physical Society* **44** (6), 52 (1999).

4.8 Membership in Professional Organizations

Advanced Computing Systems Association (USENIX): Gary Carr

American Association for Advancement of Science: Rex P. Hjelm, Robert McQueeney, Michael Oothoudt, Roger Pynn (Fellow), Robert A. Robinson, Rob Ryne, James L. Smith, Frans Trouw

American Ceramic Society: James L. Smith

American Chemical Society: Juergen Eckert, Frans Trouw

American Crystallographic Association: Robert A. Robinson, James L. Smith, Robert B. Von Dreele

American Geophysical Union: Robert B. Von Dreele

American Indian Science & Engineering Society (AISES): Don Clark

American Nuclear Society: Phillip D. Ferguson, Maurice J. Katz, Gary J. Russell

American Physical Society: Chris Allen, Goetz M. Bendele, Tarlochan Bhatia, Donald W. Brown, Jeffrey S. Bull, Paul Channell, Stanley Cohen, Luke L. Daemen, Juergen Eckert, John Faucett, Dan Fitzgerald, Robert Garnett, Geoffrey L. Greene (Fellow), David Gurd, Axel Hoffmann, William Ingalls, Kevin W. Jones, Maurice J. Katz, Thomas Kozlowski, Robert McQueeney, Ferenc Mezei, Michael Oothoudt, Michael Plum, Roger Pynn (Fellow), Joyce A. Roberts, Robert A. Robinson, Lawrence Rybarcyk, Rob Ryne, Stuart Schaller, Stan Schriber (Fellow), Joseph Sherman, Gregory S. Smith, James L. Smith, Frans Trouw, Tai-Sen Wang, Tom Wangler

American Society of Mechanical Engineers: Karen Cummings, Robert Valdiviez

American Society for Metals – ASM International: Joyce A. Roberts, James L. Smith

American Society for Nondestructive Testing: William Boedeker

American Society for Quality: John Faucett

American Vacuum Society: William Boedeker

Association for Computing Machinery: Thomas Kozlowski

Association of Old Crows (High-Power Microwave and Radio Frequency Electromagnetics Group): Denny Irion, David L. Whitfield

Canadian Association of Physicists: David Gurd

Commission on Powder Diffraction of the International Union for Crystallography: Robert B. Von Dreele, US Representative (1999-2002)
Deutsche Physikalische Gesellschaft (German Physical Society): Axel Hoffmann, Thomas Spickermann
European Academy of Sciences (Academia Europaea): Ferenc Mezei
European Physical Society: David Gurd, Ferenc Mezei
Health Physics Society: Jeffrey S. Bull
Hungarian Academy of Sciences: Ferenc Mezei
Institute of Electrical and Electronic Engineers (IEEE): Edward G. Jacobson, Thomas Kozlowski, Paul S. Lewis (senior member), Mike Lynch, Michael Oothoudt, Stan Schriber, Paul Tallerico (senior member and chair of the Los Alamos section), David Thomson, Yi-Ming Wang
International Center for Diffraction Data: Robert B. Von Dreele
International Facility Management Association: Jim Fraser
Materials Research Society: Luke L. Daemen, Rex P. Hjelm, Roger Pynn, Joyce A. Roberts, Gregory Smith, James L. Smith
Mathematical Association of America: Rozelle Wright
Mineralogical Society of America: Robert B. Von Dreele
Neutron Scattering Society of America: Luke L. Daemen, Juergen Eckert, Geoffrey L. Greene, Roger Pynn, Joyce A. Roberts, Robert A. Robinson, Gregory S. Smith, James L. Smith, Frans Trouw
Norwegian Physical Society: Roger Pynn
Society of Mexican-American Engineers and Scientists: Robert Valdiviez
System Administrators Guild (SAGE): Gary Carr
The Minerals, Metals, and Materials Society – TMS: James L. Smith

4.9 Membership on External Technical Advisory Committees

Mark Bourke (LANSCE-12): (1) IPNS Experiment Proposal Evaluation Committee (diffraction); (2) member of the Engineering Applications Working Group at SNS Knoxville meeting 11/10/98; (3) member of the VAMAS International Standards Working Group on Neutron Diffraction Residual Stress Measurements
Luke L. Daemen (LANSCE-12): reviewer for the International Science and Technology Center Projects
Juergen Eckert (LANSCE-12): member of the Instrument Advisory Committee for Backscattering Spectrometer at SNS
David Gurd (LANSCE-8): Machine Advisory Committee for KEKB, Tsukuba, Japan
Rex P. Hjelm (LANSCE-12): (1) Executive Committee Member, Instrument Advisory Team for Small-angle Scattering, SNS; (2) member of the Large Scale Structures Working Group; (3) Program Committee Member of the XI International Conference on Small-angle Scattering
Thomas Kozlowski (LANSCE-12): (1) chairman of the IEEE NPSS Computer Applications in Nuclear and Plasma Sciences Technical Committee; (2) chairman of the 1999 IEEE NPSS Real-Time Conference
Robert McQueeney (LANSCE-12): (1) visiting scientist, California Institute of Technology (1998-present); (2) member of the Spallation Neutron Source High Flux Isotope Reactor User Group Executive Committee; (3) member of the Lattice Excitations Work Group at Spallation Neutron Source Workshop on Inelastic Neutron Scattering, Argonne, IL 11/1/99
F. Mezei (LANSCE-DO): (1) SNS Instrument Oversight Committee; (2) Scientific Council of Laboratoire Leon Brillouin, Saclay, France; (3) Instrumentation Subcommittee, Institut-Laue-Langevin, Grenoble, France
Subrata Nath (SNS-PO): Chair of the Technical Advisory Committee (TAC) for the IPHI (Injecteur Proton Haute Intensite) project at CEA (Commissariat a l'Energie Atomique), Saclay, France
Mike Oothoudt (LANSCE-6): Audit Committee for the Control System of the Paul Scherrer Institute Proton Accelerator, November 1–3, 1999
Roger Pynn (LANSCE-DO): (1) Chair of the NSF site review of the Center for High Resolution Neutron Scattering (CHRNS) at the NIST Center for Neutron Research; (2) Proposal Evaluation Board of the Advanced Photon Source

Joyce A. Roberts (LANSCE-12): International Advisory Committee for the International Conference on Neutron Scattering 2001
Ray Roybal (LANSCE-1): Northern New Mexico Community College Drafting Advisory Board
Gary Russell (LANSCE-12): Target/Instrumentation Advisory Committee (TIAC) for the Oak Ridge Spallation Neutron Source (SNS) project
Rob Ryne (LANSCE-1): (1) Program Advisory Committee, National Energy Research Scientific Computing Center (committee member for DOE/OS/HENP); (2) Executive Committee of the Energy Research Scientific Computing Users Group (committee member for DOE/OS/HENP); (3) US Particle Accelerator School Advisory Committee
Stan Schriber (LANSCE-DO): (1) Linac Coherent Light Source Review Board and Steering Committee; (2) Chair of Large-Scale Accelerator Simulation Steering Committee
Greg Smith (LANSCE-12): (1) LANSCE New Instrument Proposal Evaluation Committee (PEC); (2) Advanced Photon Source CMC CAT Executive Committee; (3) IPNS Experiment Proposal Evaluation Committee (SANS and Reflectometry); (4) Target/Instrumentation Advisory Committee (TIAC) for the Oak Ridge Spallation Neutron Source (SNS) project
James L. Smith (LANSCE-12): (1) Proposal Review Panel, National High Magnetic Field Laboratory, March 1998-November 1999; (2) Brown University Alumni Association Board of Governors, Providence, RI, since September 1998; (3) Selection Committee for Chair of Experimental Condensed-Matter Physics, Uppsala University, Sweden, since May 1999
Frans Trouw (LANSCE-12): (1) IPNS Experiment Proposal Evaluation Committee (Inelastic Scattering); (2) member and spokesman for Chemistry Working Group at SNS Knoxville meeting 11/10/98; (3) chair of the Chemical Excitations Working Group at the Spallation Neutron Source Workshop on Inelastic Neutron Scattering, Argonne, IL, 11/1/99
Robert Von Dreele (LANSCE-12): (1) member of the Powder Diffraction Working Group at SNS Knoxville meeting 11/10/98; (2) member of the Liquids and Amorphous Materials Working Group at SNS Knoxville meeting 11/10/98
Thomas Wangler (LANSCE-1): (1) DARHT Technical Review Committee, Lawrence Berkeley Laboratory, March 16-18, 1999, and Los Alamos National Laboratory, November 18-19, 1999; (2) DOE Lehman Review of Next Linear Collider (NLC) Program, SLAC, May 24-28, 1999, served as Chairman of Linac Subcommittee

4.10 Membership on Editorial Advisory Boards for Professional Journals

F. Mezei (LANSCE-DO): editorial board of Journal of Neutron Research
Rob Robinson (LANSCE-12): editorial board of Journal of Neutron Research
James L. Smith (LANSCE-12): (1) member of the editorial board, Journal of Alloys and Compounds since 1985; (2) editor of Philosophical Magazine B since 1995

4.11 Professorships

Stanley Cohen (LANSCE-6): Adjunct Professor of Physics, UNM Department of Physics and Astronomy
Juergen Eckert (LANSCE-12): Adjunct Professor, Department of Chemistry, Texas A&M University
Rex P. Hjelm (LANSCE-12): Adjunct Professor, University of Illinois 1995-
Heinz Nakotte (NMSU): Joint New Mexico State University and LANSCE Professor
Roger Pynn (LANSCE-DO): Adjunct Professor, University of California, Santa Barbara
Rob Robinson (LANSCE-12): (1) Adjunct Professor at University of California Riverside, 1998-1999; (2) Adjunct Professor, New Mexico State University, 1993-
James L. Smith (LANSCE-12): (1) Adjunct Professor of Physics, Florida State University, Tallahassee, since May 1991; (2) Adjunct Professor of Physics, Boston College, Boston, since December 1997; (3) Adjunct Professor of Chemistry, Brigham Young University, in process, December 1999

APPENDIX A

Publications in Peer-Reviewed Journals

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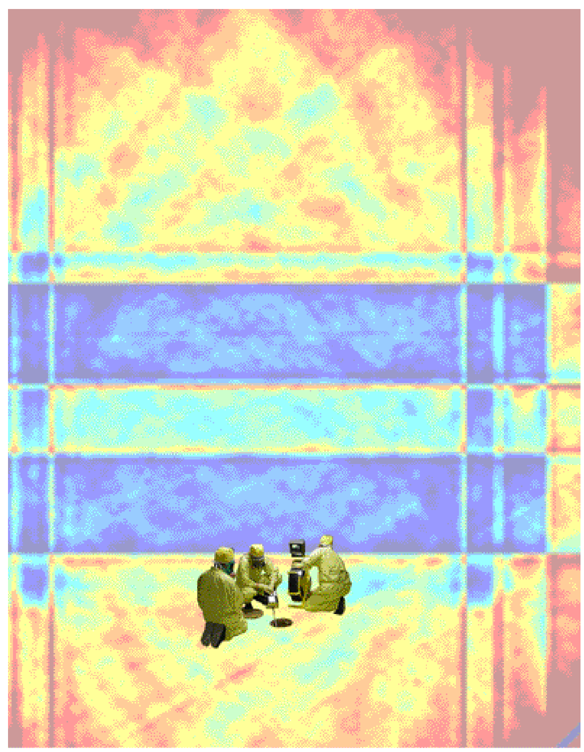
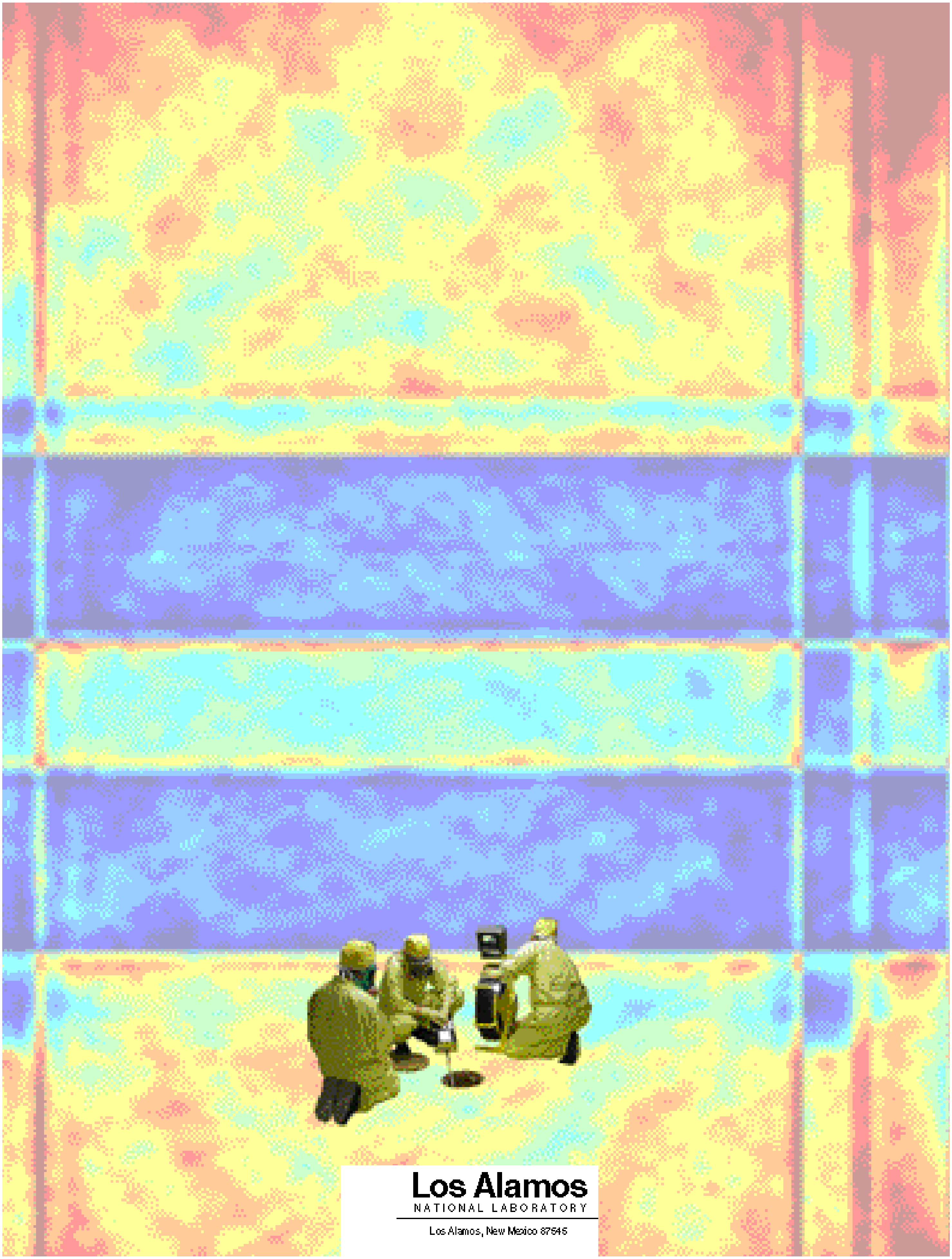


▲ *About the back cover: The background is a tomographic reconstruction from twelve fast neutron radiographs of two iron plates separated by a half-inch gap. The foreground image shows technicians cleaning out a drain in ER-1.*



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